VI. RISK ASSESSMENT

The objective of this PM health risk assessment is to provide quantitative estimates of the risks to public health associated with 1) existing air quality levels, 2) projected air quality levels that would occur upon attainment of the current PM_{10} standards, and 3) projected air quality levels that would occur upon attainment of alternative $PM_{2.5}$ standards. As an integral part of this assessment, qualitative and, where possible, quantitative characterizations of the uncertainties in the resulting risk estimates have been developed, as well as information on baseline incidence rates for the health effects considered. This assessment provides information most relevant to evaluating alternative levels of PM standards, rather than to selecting the most appropriate indicator of PM. This risk information is intended as a tool that may, together with other information presented in this Staff Paper, assist the Administrator in selecting primary PM standards that, in her judgment, would reduce risks to public health sufficiently to protect public health with an adequate margin of safety, recognizing that such standards will not be risk-free.

As discussed in section V.E above, the CD concludes that the overall consistency and coherence of the epidemiologic evidence suggests a likely causal role of ambient PM in contributing to adverse health effects (CD, p. 13-1). Also discussed in section V.E. is an alternative interpretation, suggested by some researchers, that PM may be serving as an index for the complex mixture of pollutants in urban air. The risk assessment described here is premised on the assumption that PM (measured as PM_{10} and $PM_{2.5)}$ is causally related to the health effects observed in the epidemiological studies and/or that PM is a useful index for the mixture of pollutants that is related to these effects.

In presenting this risk assessment, the staff cautions that despite the consistency and coherence of the epidemiological evidence with respect to the existence of effects, quantitative relative risk results derived from these studies include significant uncertainty. Due to the uncertainties in the concentration-response study results, as well as the many sources of uncertainty inherent in the analyses presented in this chapter, the risk estimates developed in this assessment should not be interpreted as precise measures of risk. The major uncertainties and assumptions associated with these analyses are highlighted in the following discussion and presentation of results. In addition, some key uncertainties are addressed quantitatively through individual sensitivity analyses as well as integrated uncertainty analyses which assess the combined effects of several key uncertainties.

The following sections summarize the scope of the analyses, key components of the risk model, and results of baseline risk and sensitivity analyses. A detailed discussion of the risk assessment methodology and results is presented in technical support documents (Abt Associates, 1996a,b).

A. General Scope

The PM risk analyses focus on selected health effects endpoints such as increased daily mortality, increased hospital admissions for respiratory and cardiopulmonary causes, and increased respiratory symptoms for children. Although the risk analyses could not address all of the various health effects for which there is some evidence of association with exposure to PM, all such effects are identified and considered above in section V.C. All concentration-response functions used in these analyses are based on findings from human epidemiological studies, which rely on fixed-site, population-oriented, ambient monitors as a surrogate for actual integrated PM exposures. Measurements of daily variations of ambient PM concentrations, as used in the time series epidemiological studies that provide the concentration-response relationships for these analyses, have a plausible linkage to the daily variations of exposure from ambient sources for the populations represented by ambient monitoring stations, as discussed in Chapter IV. The CD concludes that this linkage should be better for indicators of fine particles (e.g., $PM_{2.5}$) than for indicators of fine plus coarse particles (e.g., PM_{10}, TSP), and in turn, should be better than indicators of inhalable coarse fraction particles (PM_{10} - $PM_{2.5}$) (CD, p. 1-10). A more detailed discussion of the possible impact of exposure misclassification on the estimated concentration-response relationships derived from the community epidemiological studies is presented above in section V.E.

These PM risk analyses feature:

- analyses of risks under a recent 12-month period of air quality (labeled "as is" air quality) and under a situation where air quality just attains various alternative standards being considered;

- estimates of risks for the urban centers of two example cities, one eastern (Philadelphia County) and one western (Southeast Los Angeles County), rather than national estimates;

- estimates of risks only for concentrations exceeding an estimated background level; and

- qualitative and quantitative consideration of uncertainty, including sensitivity analyses of key individual uncertainties and integrated uncertainty analyses combining key uncertainties.

More specifically, consistent with the recommendations to the Agency provided in the January 5, 1996 CASAC letter to the Administrator (Wolff, 1996b), alternative 24-hr and annual $PM_{2.5}$ standards are examined alone and in combination with the current PM_{10} standards. This focus also reflects the conclusions drawn in the CD (CD, Chapter 13) that it is appropriate to consider fine and coarse fraction particles separately, and that for mortality and some measures of morbidity, the most consistent associations are seen with fine and thoracic particles (e.g., $PM_{2.5}$, PM_{10}) as compared to coarse fraction particles (CD, Chapter 13; section V.F above). The scope of these analyses initially focuses on developing risk estimates for portions of two selected urban areas: Philadelphia County and a portion (roughly the southeastern third) of Los Angeles County (hereafter referred to as "Los Angeles County"). These areas were chosen based on availability of PM_{10} and $PM_{2.5}$ air quality data, and the desire to include areas from the eastern and western parts of the United States to reflect regional differences in the makeup of PM. Finally, estimates of risks above background PM concentrations are judged to be more relevant to policy decisions about the level of ambient air quality standards than estimates that include risks potentially attributable to uncontrollable background PM concentrations.

B. Components of the Risk Model

In order to estimate the change in health effects incidence corresponding to the difference in PM levels between "as is" conditions and just attaining alternative standard scenarios, the following three key components are required for a given health endpoint and selected city: 1) air quality information, 2) concentration-response relationships, and 3) baseline health incidence rates. Figure VI-1 is a broad schematic depicting the role of these components in the risk analyses. The general health risk model which combines changes in PM air quality concentrations (Δx), the concentration-response relationships for a given health endpoint (reflected by β, the PM coefficient derived from epidemiology studies), and the baseline health effects incidence rate (y) for a given health endpoint is represented by equation 1:

Equation 1 $$\Delta y = y[e^{\beta \Delta x} - 1]$$

Estimates of risk (i.e., health effects incidences attributable to PM) are quantified for PM concentrations above background except for those studies in which the range of observed PM concentrations did not go down to estimated background (e.g., the prospective cohort mortality studies). For these studies effects are quantified down to the lowest concentrations observed in the study. As indicated in Figure VI-1, sensitivity analyses on various key inputs to the PM health risk model are conducted as part of this assessment, as well as an integrated uncertainty analysis that examines the potential impact of combining several key uncertainties. Each of these key components is briefly discussed below.

1. Air Quality Information

The air quality information required to conduct the PM risk analyses includes: 1) "as is" air quality data for both PM_{10} and $PM_{2.5}$ from population-oriented monitors for the selected cities, 2) estimates of background PM concentrations appropriate to that location, and 3) a method for adjusting the “as is” data to reflect patterns of air quality change estimated to occur when each city attains various alternative standards. Table VI-1 provides a summary of the

Figure VI-1 Major Components of Particulate Matter Health Risk Analysis

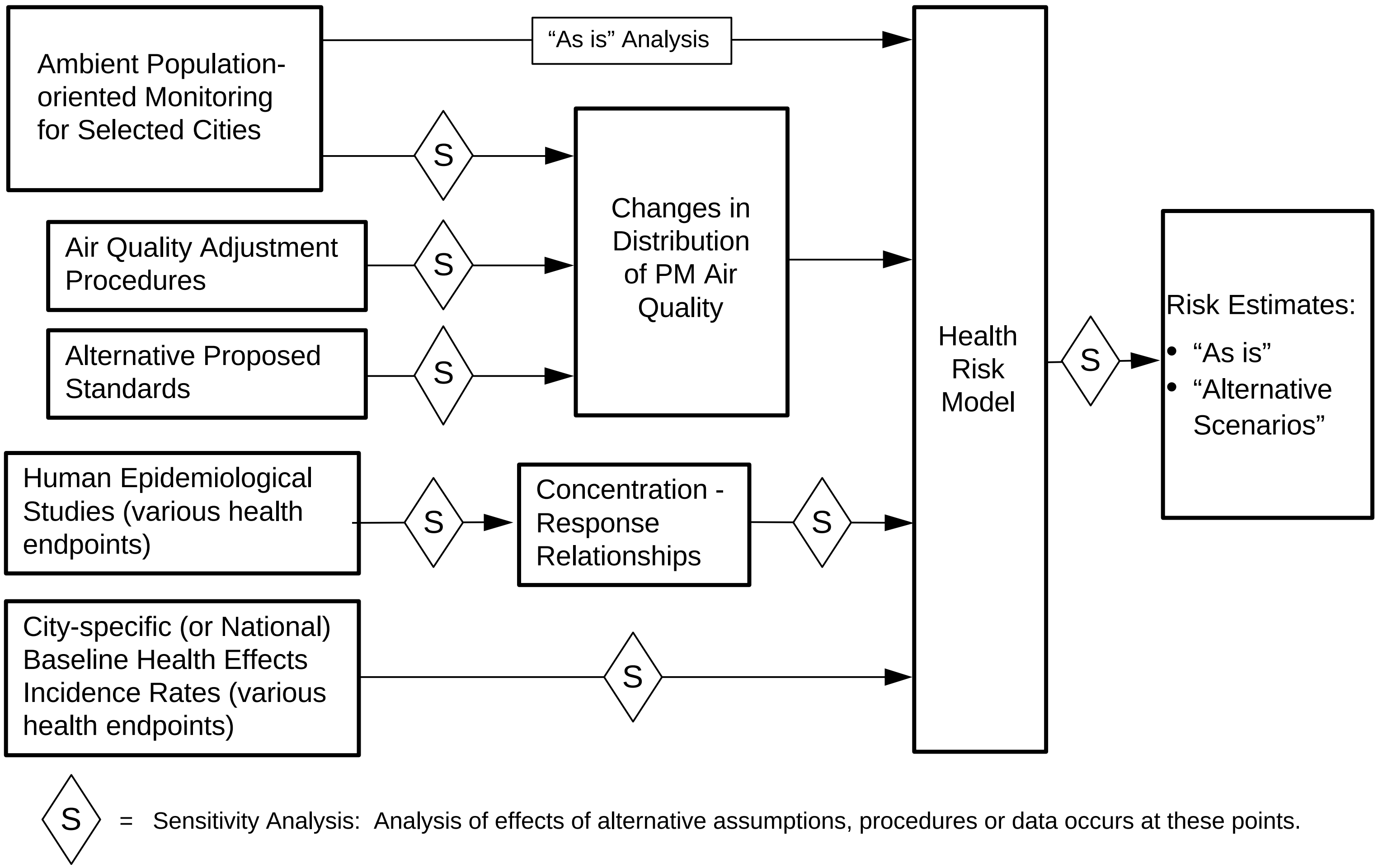


TABLE VI-1. CITIES EXAMINED IN PM RISK ANALYSIS

City	Population[a] (millions)	Year	% of Days on Which Air Quality Data are Available		PM_{10}[b]		$PM_{2.5}$[b]	
			PM_{10}	$PM_{2.5}$	Annual Average (μg/m^3)	Second Max, 24-hr Avg. (μg/m^3)	Annual Average (μg/m^3)	Second Max, 24-hr Avg. (μg/m^3)
Philadelphia County, PA	1.6	1992-93	99	96	25	77	17	72
Los Angeles County, CA	3.6	1995	59	59	52	195	30	129

[a]Based on 1990 U.S. Census data.

[b]Concentrations are reported for the monitor with the highest value.

Note: More detailed information about the air quality data in these cities is presented in Section 4 of Abt Associates (1996b).

PM_{10} and $PM_{2.5}$ air quality data for the two areas included in these analyses. The PM_{10} and $PM_{2.5}$ monitoring information for Philadelphia County are from three monitors used in the Acid Aerosol Characterization Study during 1992-1993 (network sites described in Suh et al., 1995). The monitoring information for southeast Los Angeles County comes from two dichotomous samplers operated during 1995 by the South Coast Air Quality Management District. Figure VI-2 presents frequency distributions of the daily PM_{10} and $PM_{2.5}$ concentrations in Philadelphia County based on spatially averaging the reported concentrations available from the different monitors for each day. Figures VI-3 and VI-4 show the frequency distributions of the daily PM_{10} and $PM_{2.5}$ concentrations by quarter in southeast Los Angeles County based on spatially averaging the reported concentrations available from the different monitors for each day.

As discussed above, these ambient concentrations are used as a surrogate for population exposures in these analyses, a procedure consistent with the health literature but which adds uncertainty to the risk estimates. In an effort to limit uncertainties that would result in combining data across different monitoring methods, only information from these monitors was used directly in the risk analysis.[1]

Background PM concentrations used in these analyses are defined in Chapter IV as the distribution of PM concentrations that would be observed in the U.S. in the absence of anthropogenic emissions of PM and its precursors in North America. For these analyses, an estimate of the annual average background level is desired, rather than a daily average (e.g., the maximum 24-hour level), since estimated risks are aggregated for each day throughout the year. The staff have chosen to use the midpoint of the appropriate ranges of annual average estimates for PM background presented in Table IV-3 for the base case risk estimates (i.e.,

---

[1]Although not directly used in the risk analyses, information from the AIRS database for sites in Los Angeles county was used to help define the region of Los Angeles County included in this analysis (see Abt Associates, 1996b).

Figure VI-2. Daily Average PM Concentration Frequencies

Philadelphia County, September 1992 - August 1993

Figure VI-3. Daily Average PM-10 Concentrations for Southeast Los Angeles County, 1995

Figure VI-4. Daily Average PM-2.5 Concentration Frequencies For Southeast Los Angeles County, 1995

eastern values are used for Philadelphia and western values for Los Angeles):

- For PM$_{10}$: 5 - 11 μg/m^3 for Philadelphia, and 4 - 8 μg/m^3 for Los Angeles
- For PM$_{2.5}$: 2 - 5 μg/m^3 for Philadelphia, and 1 - 4 μg/m^3 for Los Angeles.

Sensitivity analyses have been done using the appropriate lower and upper ends of the above ranges to characterize the impact of this model input choice on the risk estimates.

To estimate health risks associated with just attaining alternative PM$_{2.5}$ standards, it is necessary to estimate the PM concentrations that would occur under each alternative standard. When assessing the risks associated with long-term epidemiological studies that use an annual average concentration level, the annual mean is simply set equal to the standard level. In contrast, when assessing the risks associated with short-term epidemiological studies, the distribution of 24-hour values that would occur upon just attaining a given 24-hour PM standard has to be simulated. While there are many different methods of reducing daily PM levels, preliminary analysis found that PM levels have in general historically fluctuated in a proportional manner (i.e., concentrations at different points in the distribution of 24-hour PM values have decreased by approximately the same percentage) (Abt Associates, 1996b). Therefore, attainment of the current PM$_{10}$ and alternative PM$_{2.5}$ daily standards has been simulated by adjusting the "as is" air quality data using a proportional rollback approach (i.e., concentrations are reduced by the same percentage) for concentrations exceeding the estimated background level (see Abt Associates, 1996b). Sensitivity analyses have been conducted to examine alternative air quality adjustment procedures (e.g., a method that reduces the top 10% of daily PM concentrations more than the lower 90%).

2. Concentration-Response Functions

The second key component in the risk model is the set of concentration-response relationships which provide estimates of the relationship between each health endpoint of interest and ambient PM concentrations. Table VI-2 summarizes the selected epidemiological studies which are judged adequate by the CD to provide estimated concentration-response relationships for a variety of health endpoints associated with elevated PM$_{10}$ and/or PM$_{2.5}$ exposures (CD, Tables 13-3, 13-5). Only studies based on either PM$_{10}$ and/or PM$_{2.5}$ as a measure of PM have been used in these analyses. Each study provides an estimate of relative

Table VI-2. Selected Epidemiological Studies and Associated Relative Risk Estimates Used in Risk Analyses

Health Effect	PM Indicator	Study Location	Reported PM Levels ($\mu g/m^3$) Mean (Range)[1]	Estimated Relative Risk[2] (95% Confidence Interval)	Pooled Relative Risk[3]
TOTAL MORTALITY					
Short-term Exposures	PM_{10}	Six Cities[a]			
		Portage, WI	18 (±11.7)	1.04 (0.98, 1.09)	
		Boston, MA	24 (±12.8)	1.06 (1.04, 1.09)	
		Topeka, KS	27 (±16.1)	0.98 (0.90, 1.05)	
		St. Louis, MO	31 (±16.2)	1.03 (1.00, 1.05)	
		Kingston/Knoxville, TN	32 (±14.5)	1.05 (1.00, 1.09)	1.04 (0.99, 1.09)
		Steubenville, OH	46 (±32.3)	1.05 (1.00, 1.08)	
		Chicago, IL[b]	38 (NR/128)	1.03 (1.02, 1.04)	
		Utah Valley, UT[c]	47 (11/297)	1.08 (1.05, 1.11)	
		Birmingham, AL[d]	48 (21,80)	1.05 (1.01, 1.10)	
		Los Angeles, CA[e]	58 (15/177)	1.03 (1.00, 1.06)	
	$PM_{2.5}$	Six Cities[a]			
		Portage, WI	11.2 (±7.8)	1.03 (0.99, 1.07)	
		Topeka, KS	12.2 (±7.4)	1.02 (0.95, 1.09)	
		Boston, MA	15.7 (±9.2)	1.06 (1.04, 1.07)	1.04 (1.00, 1.07)
		St. Louis, MO	18.7 (±10.5)	1.03 (1.01, 1.04)	
		Kingston/Knoxville, TN	20.8 (±9.6)	1.04 (1.01, 1.07)	
		Steubenville, OH	29.6 (±21.9)	1.03 (1.00, 1.05)	
Long-term Exposures	$PM_{2.5}$	ACS Study[f] (50 U.S. SMSA)	9-34[4]	1.17 (1.09, 1.26)	---
HOSPITAL ADMISSIONS -- Short-term Exposures					
All Respiratory Causes (for Elderly > 64 years)	PM_{10}	Tacoma, WA[g]	37 (14, 67)	1.10 (1.03, 1.17)	
		New Haven, CT[g]	41 (19, 67)	1.06 (1.00, 1.13)	1.09 (1.02, 1.19)
		Cleveland, OH[h]	43 (19, 72)	1.06 (1.00, 1.11)	
		Spokane, WA[i]	46 (16, 83)	1.08 (1.04, 1.14)	
	$PM_{2.5}$	Toronto[j]	18.6 (NR/66.0)	1.15 (1.02, 1.28)	

Health Effect	PM Indicator	Study Location	Reported PM Levels ($\mu g/m^3$) Mean (Range)[1]	Estimated Relative Risk[2] (95% Confidence Interval)	Pooled Relative Risk[3]
HOSPITAL ADMISSIONS -- Short-term Exposures					
COPD (for Elderly > 64 years)	PM_{10}	Minneapolis, MN[k] Birmingham, AL[l] Spokane, WA[i] Detroit, MI[m]	36 (18,58) 45 (19,77) 46 (16,83) 48 (22,82)	1.25 (1.10, 1.44) 1.13 (1.04, 1.22) 1.17 (1.08, 1.27) 1.10 (1.02, 1.17)[5]	1.14 (1.05, 1.31)
Ischemic Heart Disease (for Elderly > 64 years)	PM_{10}	Detroit, MI[n]	48 (22,82)	1.02 (1.01, 1.03)	---
Congestive Heart Failure (for Elderly > 64 years)	PM_{10}	Detroit, MI[n]	48 (22,82)	1.03 (1.01, 1.05)	---
Pneumonia (for Elderly > 64 years)	PM_{10}	Minneapolis, MN[k] Birmingham, AL[l] Spokane, WA[i] Detroit, MI[m]	36 (18,58) 45 (19,77) 46 (16,83) 48 (22,82)	1.08 (1.01, 1.15)[5] 1.09 (1.03, 1.15) 1.06 (0.98, 1.13) 1.06 (1.02, 1.10)[5]	1.07 (1.01, 1.14)
RESPIRATORY SYMPTOMS					
Lower Respiratory Symptoms in Children: Short-term Exposures	PM_{10}	Six Cities[o] Utah Valley, UT[p]	30 (13,53) 46 (11/195)	2.03 (1.36, 3.04)[6] 1.28 (1.06, 1.56)	---
	$PM_{2.5}$	Six Cities[o]	18.0 (7.2-37)	1.44 (1.15-1.82)[6]	---
Bronchitis in Children: Long-term Exposures	$PM_{15/10}$	Six Cities[g]	20-59[4]	3.26 (1.13, 10.28)[6]	---

References:

[a]Schwartz et al. (1996a)
[b]Ito and Thurston (1996)
[c]Pope et al. (1992)
[d]Schwartz (1993a)
[e]Kinney et al. (1995)
[f]Pope et al. (1995)
[g]Schwartz (1995)
[h]Schwartz et al. (1996b)
[i]Schwartz (1996)
[j]Thurston et al. (1994b)
[k]Schwartz (1994f)
[l]Schwartz (1994e)
[m]Schwartz (1994d)
[n]Schwartz and Morris (1995)
[o]Schwartz et al. (1994)
[p]Pope et al. (1991)
[q]Dockery et al. (1989)

Endnotes:

1. Range of 24-hour PM indicator level shown in parentheses is typically either the standard deviation ($\pm$ S.D.) or 10th and 90th percentiles.
2. Based on a 50 $\mu g/m^3$ increase for PM_{10} studies, and a 25 $\mu g/m^3$ increase in $PM_{2.5}$ studies.
3. See Abt Associates (1996b) for calculation method.
4. Range of city means of PM levels.
5. Only RR reported includes other pollutants in model.
6. Odds ratio.

risk (β), along with a measure of the uncertainty (95% confidence interval) of the estimate, associated with specific changes in PM levels (i.e., a 50 $\mu g/m^3$ increase in PM_{10} or a 25 $\mu g/m^3$ increase in $PM_{2.5}$).

As indicated in the CD, the most credible approach to risk analysis would be to use site-specific relative risk (RR) estimates for PM (CD, p.13-87). For Los Angeles County, site-specific RRs are available from two studies (Kinney et al, 1995; Ostro et al., 1995). Philadelphia County has been the location of several studies reporting associations between PM and mortality and hospital admissions, but none of the published reports have used PM_{10} or $PM_{2.5}$. Since site-specific relative risks are not available for all endpoints in both locations (and in the absence of more information concerning which individual studies might most appropriately characterize the health risk in a risk analysis location), an approach was employed which combined available information from all the key studies for a health endpoint. A form of meta analysis (referred to as a "pooled analysis" in this Staff Paper) was conducted which combined the results of the various studies. For comparison purposes, Table VI-2 lists the mean estimate of RR from the pooled analysis along with the RRs for the individual studies comprising the pooled analysis.

Given differences in population, particle size distribution, and other environmental stressors (e.g., weather variables, co-pollutants), RRs may be expected to vary from location to location. The CD notes such variation appears to be observed in coefficients for mortality associated with short-term exposures, and cautions against the application of a single "best estimate" relative risk value across various locations (CD, p.13-87). The pooled analyses in this risk analysis have utilized an "empirical Bayes" approach in an effort to more fully reflect the range of relative risk estimates, and accompanying statistical uncertainty, seen from location to location. Standard meta analysis techniques, such as a random effects meta analysis, estimate a mean relative risk and the statistical uncertainty around that mean estimate. The empirical Bayes approach estimates the underlying distribution of RRs observed across
areas and the likelihood that any relative risk estimate from that distribution will be applicable to an uninvestigated location. The empirical Bayes approach uses the random effects model

framework, in which the relative risks from different locations can be genuinely different, while adjusting the relative risk and statistical uncertainty observed in individual locations to some degree to reflect the information available from the entire set of studies (see Abt Associated, 1996b, for further details). However, the distribution of RRs from the empirical Bayes approach provides uncertainty estimates ("credible intervals") which are intended to represent the range of reported RRs (and not simply the uncertainty around a mean estimate) and is not restricted to assuming a normal distribution (see Abt Associates, 1996b, Exhibit 5.12). As a result, credible intervals from the empirical Bayes approach are typically wider than confidence intervals from random effects meta analysis[2] and are expected to more fully convey information on both statistical uncertainty and potential inherent differences (due to different population characteristics, PM size distributions, etc.) in the RRs for different geographic locations.[2]

In the risk analyses, the 5th and 95th percentile values from the distributions of RRs estimated by the empirical Bayes approach are provided as a 90% "credible interval" to characterize uncertainty in the risk estimates for each endpoint. (In Table VI-2, the 95% credible interval around the pooled relative risk estimate is provided instead, to facilitate comparison with the reported RRs from the original studies). In the risk analyses the mean of the distribution based on the empirical Bayes approach is also reported as an estimate of the central tendency of the distribution. Because a random effects framework was used for the empirical Bayes approach, this mean estimate is identical to what would be estimated by a random effects meta analysis. A more detailed description of the techniques used to develop the pooled estimates and the application of the empirical Bayes approach is provided in the technical support document (Abt Associates, 1996b).

In the absence of site-specific RRs for all the endpoints of interest (a product of data limitations that preclude constraining the assessment solely to those areas where both adequate air quality and concentration-response information are available), pooled analyses using this

---

[2] Exhibit 5.10 of Abt Associates (1996b) shows that the credible intervals resulting from the empirical Bayes approach are wider for cases in which a number (6-10) of location-specific concentration-response relationships are available (e.g., mortality associated with short-term exposures of PM_{10} or $PM_{2.5}$), but not substantially different for hospital admissions endpoints for which fewer studies (3-4) were pooled.

empirical Bayes approach is one method employed to allow potential differences in RR from location to location to be reflected in the risk estimates. As an additional approach, sensitivity analyses have been performed evaluating the effects of including alternative studies or excluding studies or groups of studies from the pooled analyses (Appendix F, Table F-4; Abt Associates, 1996b).

The CD identifies the interpretation of specific concentration-response relationships as the most problematic issue for risk assessment purposes at this time due to the absence of clear evidence regarding mechanisms of action for the various health effects of interest (CD, p.13-87). The reported study results used in these analyses are based on linear models extending over the range of air quality within the study, as illustrated in Figure VI-**5** (CD, Figure 13-5) by Line A. This model implies a possible linear, no-threshold underlying relationship potentially extending to zero PM concentrations (illustrated by Line B). Alternatively, the existing data do not rule out the possible existence of an underlying non-linear, threshold relationship (illustrated by Line C). Although these alternative interpretations of study results could significantly affect estimated risks, only very limited information is available to aid in resolving this issue (CD, pp. 13-87-91). Thus, the approach taken in this risk assessment is to address alternative models through sensitivity and integrated uncertainty analyses to develop ranges of estimated risks, rather than characterizing any of the sets of risk estimates as representing best estimates.

To frame the sensitivity analyses of concentration-response models, the results from various studies have been examined through a number of alternative approaches to identify appropriate PM concentration “cutpoints”[3] which define the lower end of the range over which the concentration-response functions would be applied. Table VI-3 summarizes the cutpoints examined in the sensitivity and integrated uncertainty analyses. A more detailed discussion of the basis for selecting these particular cutpoints is presented in Appendix E.

---

[3] “Cutpoint” as used in Chapter VI refers to concentrations determined to be of interest for evaluating the sensitivity of risk estimates to assumptions about the shape of concentration-response relationships. This is in contrast to the use of the term “cutpoint” in Chapter IV, which refers to the aerodynamic diameter of particles being sampled by a monitor.

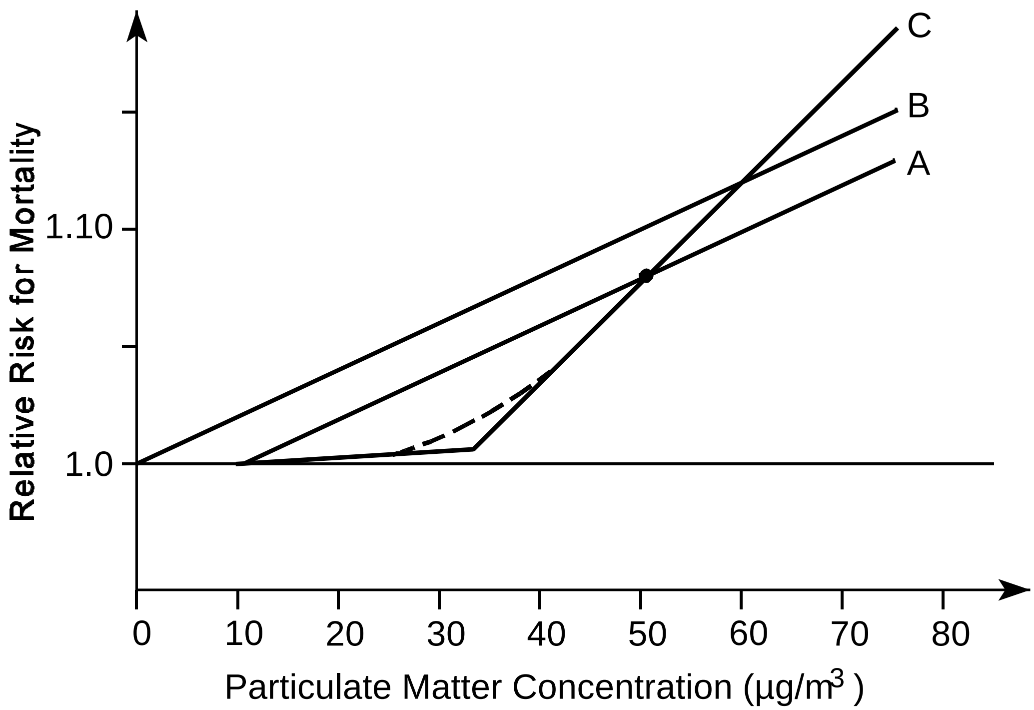


Figure VI-5. Schematic Representation of Alternative Interpretations of Reported Epidemiologic Relative Risk (RR) Findings with Regard to Possible Underlying PM Mortality Concentration-Response Functions (CD, Figure 13-5). Published studies typically only report results from linear models that estimate RR over a range of observed PM concentrations as represented by Line A (specific PM values shown are for illustrative purposes only), compared against baseline risk (RR = 1.0) at the lowest observed PM level. One alternative interpretation is that the RR actually represents an underlying linear, no-threshold PM-mortality relationship (Line B) with the same slope as Line A but extending below the lowest observed PM level essentially to 0 $\mu g/m^3$. Another possibility is that the underlying functional relationship may have a threshold (illustrated by Curve C), with an initially relatively flat segment, not statistically distinguishable from the baseline risk (1.0) until some PM concentration where it sharply increases (or more likely somewhat less sharply ascends in the vicinity of the breakpoint as shown by the dashed lines).

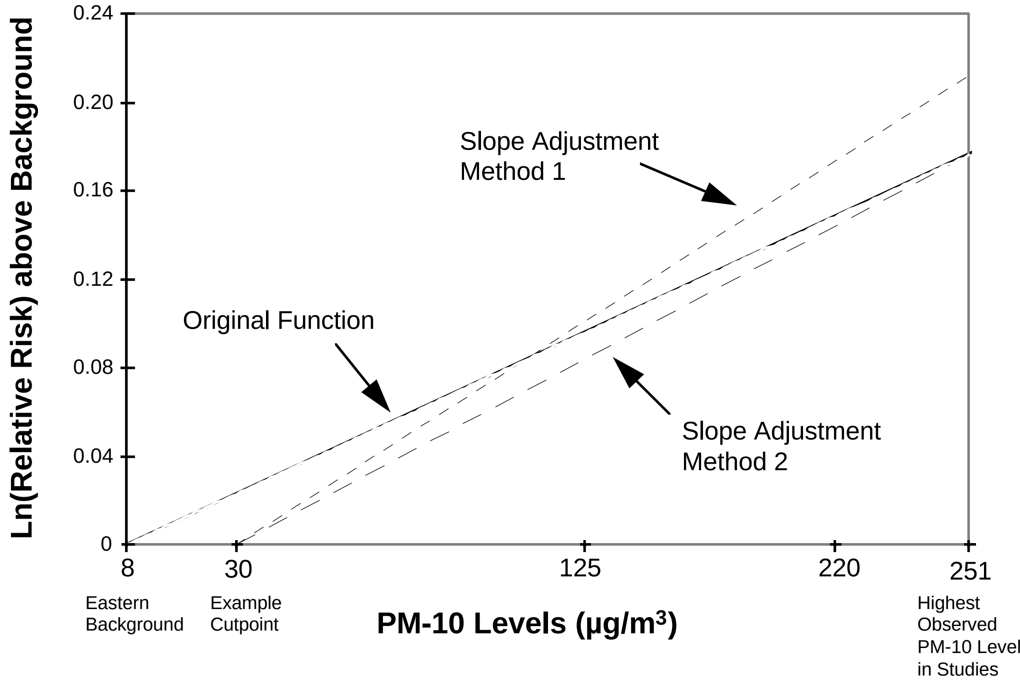
Table VI-3. Concentration-Response "Cutpoints" Examined in Uncertainty Analyses

Pollutant	Health Effects	Cutpoints Examined ($\mu g/m^3$)		
PM_{10}	Effects Associated with Short-Term Exposure	20	30	40
$PM_{2.5}$	Effects Associated with Short-Term Exposure	10	18	30
$PM_{2.5}$	Effects Associated with Long-Term Exposure	12.5	15	18

In conjunction with defining such concentration cutpoints, the slopes of the concentration-response functions have been increased to reflect the effect of potential thresholds at the selected levels. This concept that the slope above a cutpoint would be expected to increase somewhat in a threshold model is illustrated by the comparison of linear and nonlinear models applied, for example, to the TSP data set from Philadelphia presented in the CD (CD, Table 13-6; Appendix F, Figure F-1). Figure VI-6 illustrates the two methods used to adjust slopes when nonlinear models with cutpoints were applied in the risk analyses. The first method adjusts the slope of the relationship from the cutpoint to the maximum concentration observed in the health effects studies so that the area under this line is the same as the area under the original concentration-response relationship that went down to estimated background. To compensate for fewer PM-associated health effects at low concentrations (and no effects below the cutpoint level), the adjusted function must rise more rapidly than the original function. The second slope adjustment method assumes that the RR associated with the maximum concentration observed in the studies is the same as in the original function and, therefore, the concentration-response relationship extends from the cutpoint to the RR observed at the maximum concentration in the original study. This second method increases the slope less than the first method. It is important to recognize that the two adjustment

Figure VI-6. Slope Adjustment Methods Used in Sensitivity and Uncertainty Analyses

(PM-10 Pooled Mortality Function)



Relative Risks shown are the risks associated with elevated PM-10 levels relative to the risks associated with the background PM level (8 µg/m^3) for Philadelphia County.

methods are illustrative and intended to roughly bound the potential impact on concentration-response relationships if cutpoints or thresholds above background exist.

Based on this examination of study results, presented in Appendix E, the cutpoints identified in Table VI-3 have been selected as a basis for a series of sensitivity and uncertainty analyses. Results of sensitivity and uncertainty analyses involving cutpoint and other important uncertainties are presented in section VI.C below.

An additional issue concerning the appropriate interpretation of ambient PM concentration-response relationships is whether they may represent effects resulting from the combined exposure to ambient and indoor particles (or some subset of ambient and indoor exposures, such as the combined exposure to ambient and indoor combustion source particles). While total personal exposure to ambient and indoor particles can be substantially higher than exposure to ambient particles alone[4], the CD concludes that additional exposure to particles indoors from sources independent of ambient sources (which individuals can be exposed to when either outdoors or indoors, since particles penetrate residential indoor microenvironments (CD, p. 1-9)) would not be expected to systematically affect coefficients of ambient concentration-response relationships (CD, p. 1-10).

3. Baseline Health Effects Incidence Rates

The third key component required in the PM risk analyses is an estimate of the baseline health effects incidence rate corresponding to "as is" PM levels. Incidence rates express the occurrence of a disease or event (e.g., asthma episode, hospital admission, death) in a specified time period, usually per year. Health effects incidence rates vary among geographic areas due to differences in population characteristics (e.g., age distribution) and factors affecting illness or response (e.g., smoking, occupation, income levels, air pollution levels).

[4]For example, the PTEAM study found that for a study population in Riverside, CA, during a period in which daytime ambient PM_{10} concentrations measured at a central monitor averaged 91 $\mu g/m^3$ and ranged from 37 - 158 $\mu g/m^3$ (10th -90th percentile of daytime concentration distribution), daytime total personal exposure averaged approximately 60% higher (150 $\mu g/m^3$, ranging from 60 - 263 $\mu g/m^3$ (10th -90th percentile) (Clayton et al, 1993). However, nighttime ambient and personal exposures were highly similar [mean concentrations were identical (77 $\mu g/m^3$) with ambient PM_{10} values ranging slightly above and below personal exposure values across the group (10th-90th percentile range 30 -156 $\mu g/m^3$ ambient; 37 - 135 $\mu g/m^3$ personal)].

Tables VI-4 and VI-5 provide a summary of population estimates and baseline mortality and morbidity incidence rates used in these analyses for Philadelphia and Los Angeles Counties. Mortality rates are based on county-specific data from the National Center for Health Statistics. Morbidity rates for hospital admissions in Philadelphia are based on Philadelphia County admissions data obtained from the Delaware Valley Hospital Council, and for Los Angeles County from California's Office of Statewide Health Planning and Development. For respiratory symptoms, baseline incidence information on symptoms is not routinely reported, so for these endpoints the incidence rates from the studies themselves were used. This would be expected to introduce considerable uncertainty, since baseline symptoms incidence would be expected to vary across locations, and because many diary studies (e.g., Schwartz et al., 1994; Pope et al., 1991) do not record symptoms incidence across an entire year. Thus, incidence estimates for respiratory symptoms are particularly uncertain and are primarily included to provide perspective on the number of effects estimated relative to other health effects.

Uncertainty in baseline incidence rates primarily affects estimates of numerical incidence (e.g., counts of number of hospital admissions, symptoms). Percent of incidence estimates can be obtained without the use of baseline incidence health information, since almost all of the key studies used in the risk analysis report results in the form of RR versus air quality (the exception being Thurston et al., 1994) which generate the same percent of incidence estimates regardless of the baseline incidence rates. Baseline incidence rates are only involved in estimating the implication of the estimates of percentage incidence in terms of numbers of health effects.

Table VI-4. Relevant Population Sizes for Philadelphia County and Southeast Los Angeles County

Population	Philadelphia County	Southeast Los Angeles County
Total	1,590,000	3,640,000
Ages $\geq$ 65	241,000 (15.2%)	322,000 (8.9%)
Children, ages 8-12	103,000 (6.5%)	282,000 (7.8%)
Children, ages 10-12	62,000 (3.9%)	166,000 (4.6%)
Asthmatic Children, ages 9-11	3,900* (0.3%)	10,700* (0.3%)
Asthmatic African-American Children, ages 7-12	--	1,800* (0.05%)

*Incidences for asthmatic children were obtained using the national asthma prevalence among children (6.3%). The incidence of asthmatic African-American children ages 7-12 in Southeast L.A. County, for example, is 3,640,000 multiplied by {0.0937 (the proportion of the population that is ages 7-12) x 0.085 (the proportion of the population that is African-American) x 0.063 (the proportion of the national population of children that are asthmatic)}.

Table VI-5. Baseline Health Effects Incidence Rates

Health Effect	Philadelphia County	Southeast Los Angeles County	National Average[a]
Mortality[b] (per 100,000 general population/year)	1280	667	830
Morbidity:			
A. Hospital Admissions (per 100,000 general population/year)			
Total respiratory hospital admissions[c] (all ages): ICD codes 466, 480-482, 485, 490-493	816	427	--
Total respiratory hospital admissions (65 and older): ICD codes 460-519	650	428	504
COPD admissions (65 and older): ICD codes 490-496	202	116	103
Pneumonia admissions (65 and older): ICD codes 480-487	257	205	229
Ischemic heart failure (65 and older): ICD codes 410-414	614	307	450
Congestive Heart Disease (65 and older): ICD code 428	487	197	231
B. Respiratory Symptoms (percent of relevant population)			
Lower Respiratory Symptoms (LRS) in children, ages 8-12 (number of cases of symptoms per day)	0.15%*	0.15%*	--
Lower Respiratory Symptoms (LRS) in asthmatic children, ages 9-11 (number of days of symptoms)	16%*	16%*	--
(Doctor diagnosed) acute bronchitis in children ages 10-12 per year	6.5%*	6.5%*	--

All incidence rates are rounded to the nearest unit.
a. National rates for hospital admissions for patients over 64 years of age were obtained from Vital and Health Statistics, Detailed Diagnoses and Procedures, National Hospital Discharge Survey, 1990. June, 1992. CDC. Hyattsville, Md. Each rate is based on the number of discharges divided by the 1990 population of 248,709,873 .
b. Mortality figures exclude suicide, homicide, and accidental death, which corresponds to the measures used in the epidemiological studies employed in this analysis.
c. Although a baseline incidence rate is not needed for calculating the incidence of total respiratory hospital admissions associated with PM (because the concentration-response function is linear), it is needed for calculating the percent change in incidence associated with PM.

*Baseline incidence rates for respiratory symptoms were taken from the original studies: Schwartz et al. (1994): percent of all child-days on which there were respiratory symptoms, as defined in the study; Pope et al. (1991): for number of days of LRS in asthmatic children ages 10-12; and Dockery et al. (1989), for acute bronchitis in white children ages 10-12.

4. Limitations and Uncertainties

This PM health risk assessment involves substantial uncertainties given the nature of the pollutant, limited data on population exposures, and the nature of the epidemiological evidence of effects. The major uncertainties include:

- Limited information on air quality and on human activity patterns (e.g., how they vary over time and location compared to the original studies) add uncertainty to the analyses. Errors in measurement of relevant air quality, both instrument error in monitored concentrations and errors resulting from using averages of population-oriented monitors to represent population exposure, are potentially important sources of uncertainty.
- Modeled air quality simulations of attainment of alternative PM standards introduce potentially significant uncertainties, particularly in assessing the impact of alternative standards with regard to the pattern of reductions that would be observed across the distribution of air quality values.
- The use of uncertain estimates of annual average background PM concentration for each location results in uncertainties with regard to estimates that are representative of risks in excess of those potentially attributable to uncontrollable background PM levels.
- Insufficient information exists to fully assess the extent to which PM concentration-responses functions reflect the best estimates of risk associated with PM, as well as whether such functions are transferable across cities due to (1) variations in PM composition across cities, (2) the possible role of associated copollutants in influencing PM risk, and (3) variations in the relation of total exposure to ambient monitoring in different locations. There also is the additional uncertainty concerning the transferability of health functions to future PM aerosol mixes.
- The use of pooled concentration-response functions from studies in several locations to represent the overall effect of particles on a particular health endpoint in any one location introduces uncertainty.
- The impact of historical air quality on estimates of health risk from long-term PM exposures is not well understood, nor is the duration of time that a reduction in particle

concentrations must be maintained in a given location in order to experience the predicted reduction in health risk.

- Normalizing the health risk experienced or reduced in different locations due to differences in the completeness of the air quality data sets introduces uncertainty.
- Additional uncertainty is related to baseline health effects incidence information, particularly where location specific information is not available and must be estimated either by scaling national incidence rates or using reported rates from the original studies. Uncertainties in baseline health information would be expected to affect numerical estimates of total incidence more than estimates of the percentage of incidence.

Sensitivity and uncertainty analyses addressing many of these uncertainties are presented along with the PM risk estimates in the following section and in Appendix F.

C. Risk Estimates for Philadelphia and Los Angeles Counties

In the sections below risk estimates are first presented for the two locations analyzed using base case assumptions associated with "as is" PM levels. Risk estimates are then presented for Los Angeles County with PM levels adjusted to just attain the current PM_{10} standards using base case assumptions. Finally, risk estimates are presented associated with attainment of alternative $PM_{2.5}$ standards. For each of these cases, the potential impacts of alternative assumptions and uncertainties inherent in the risk assessment are examined in sensitivity analyses of individual key uncertainties and in an integrated uncertainty analysis that looks at the combined effect of several uncertainties.

1. Base Case Risk Estimates Associated with "As Is" PM Levels

The estimated health risks associated with exposure to short- and long-term ambient particle concentrations in Philadelphia County and Los Angeles County have been estimated using base case assumptions, as discussed in Section VI-B, for recent 12 month periods. Estimates for health risks posed by ambient particles measured both as PM_{10} and $PM_{2.5}$ are provided. The risk estimates for PM_{10} and $PM_{2.5}$ should be viewed as providing alternative estimates of the total health impacts of particles for the health endpoints listed in the Tables. The risk estimates for the two different measures of PM should not be summed. The estimates are for annual health risks from particle concentrations above estimates of annual background concentrations (8 µg/m^3 PM_{10} and 3.5 µg/m^3 $PM_{2.5}$ in Philadelphia County, 6 µg/m^3 PM_{10} and 2.5 µg/m^3 $PM_{2.5}$ for Los Angeles County).

These risk estimates of effects associated with particles have been restricted to those endpoints where associations between particles and health endpoint have been demonstrated in U.S. and Canadian cities (CD, p.13-36). Risk estimates for other health endpoints reported to be associated with short-term PM_{10} concentrations, such as emergency room visits for asthma (Schwartz et al., 1993), respiratory hospitalization in children (Pope, 1991), school absences (Ransom and Pope, 1992), symptoms of cough (Schwartz et al., 1994; Ostro et al., 1991; Pope and Dockery, 1992), and asthma medication usage (Pope et al., 1991), or associated with short-term $PM_{2.5}$ concentrations, such as respiratory-related restricted activity days and work loss days in adults (Ostro and Rothschild, 1989) have not been developed. Risk estimates also have not been developed for some health endpoints reported to be associated with long-term PM concentrations, such as chronic bronchitis in adults (Abbey et al., 1995a) and decreased lung function in children (Raizenne et al., 1996) In addition, risk estimates have not been extended to different age groups from those in the original study, even though this means often estimating risks for only narrow age groups of children.[5]

a. Philadelphia County

Base case risk estimates presented in Table VI-6 suggest that PM is associated with between 1.1-1.8% (90% credible intervals (CrI) = 0.8-1.4% to 1.1-2.5%) of total mortality for short-term exposures and with about 4.6% (CrI 2.8-6.2%) of total mortality for long-term exposures in Philadelphia County. The risk estimates associated with long-term exposure are likely to reflect both a component of mortality from short-term exposures as well as mortality not tightly linked to daily changes in PM concentrations. Expressed in terms of number of deaths, the mortality incidence in Philadelphia County estimated to be associated with PM

[5]However, for studies of respiratory symptoms in Caucasian children which were restricted to exclude racial differences for analytical purposes (Schwartz et al., 1994; Pope et al., 1991; Dockery et al., 1989) the resulting concentration-response relationships were applied to the whole population of children in the pertinent age group (children 8-12, 0-11, and 10-12 years old, respectively) in the two cities examined for the risk analysis.

ranges from 220 deaths (CrI 160-290) associated with short-term exposures to 920 deaths (CrI 580-1260) associated with long-term exposures.

Base case morbidity risk estimates associated with “as is” PM levels in Philadelphia county are approximately 2.4% (CrI 1.5-3.3%) of total respiratory hospital admissions for individuals over 64 based on a pooled analysis of studies using PM_{10} as the pollutant indicator. This compares to an estimated risk of 2.0% (CrI 0.5-3.5%) of total respiratory hospital admissions for all ages in Philadelphia County based on a single study using $PM_{2.5}$ as the pollutant indicator. Risks associated with PM exposure range from 0.7-1.4%(CrI 0.3-1.2 to 0.7-2.1%) of cardiac hospital admissions among individuals over 64 years of age for ischemic heart disease and congestive heart failure.

Risks associated with short-term exposures to PM range from 6.8% (CrI 2.4-10.9%) to 20.1% (CrI 10.3-28.3%) of the lower respiratory symptoms reported in children 8-12 years in age, depending on PM indicator and the exact ages and asthma status of the children. Long-term exposure to PM over the course of the year was estimated to be associated with a 0.3% (CrI 0-0.6%) increase in incidence of doctor diagnosed acute bronchitis among 10-12 year olds.

b. Los Angeles County

Base case risk estimates associated with “as is” PM levels in Los Angeles County are presented in Table VI-7. The PM_{10} and $PM_{2.5}$ annual concentrations are approximately double the PM concentrations in Philadelphia (annual mean concentration of approximately 52 $\mu g/m^3$ PM_{10} and 30 $\mu g/m^3$ $PM_{2.5}$ in Los Angeles County versus 25 $\mu g/m^3$ PM_{10} and 17 $\mu g/m^3$ $PM_{2.5}$ for Philadelphia). Risks associated with “as is” particle levels in Los Angeles County are estimated to range from 1.6-3.7% (CrI 0.2-3.1% to 0.8-6.3%) of total mortality for short-term exposure and to be approximately 11.9% (CrI 7.5-16.0%) of total mortality for long-term exposure. The estimate of 1.6% of total mortality is based on a study of mortality in Los Angeles County (Kinney et al., 1995). This lower estimate of mortality incidence may be due in part to the fact that this study employed the shortest averaging time (1 day) of those included in the pooled estimate (CD, p.12-72).

Table VI-6. Estimated Annual Health Risks Associated with "As Is" PM Concentrations in Philadelphia County, September 1992- August 1993 (for base case assumptions)

Health Effects*			Health Effects Associated with PM-10 Above Background**		Health Effects Associated with PM-2.5 Above Background**	
			Incidence	Percent of Total Incidence	Incidence	Percent of Total Incidence
Mortality (all ages)	(A) Associated with short-term exposure		220 (160 - 290)	1.1% (0.8 - 1.4)	370 (220 - 510)	1.8% (1.1 - 2.5)
	(B) Assoc. with long-term exposure (51 locations)		-- -- -- -- -- --	-- -- -- -- -- --	920 (580 - 1260)	4.6% (2.8 - 6.2)
Hospital Admissions Respiratory	(C) Total Respiratory (all ages)		-- -- -- -- -- --	-- -- -- -- -- --	260 (70 - 450)	2.0% (0.5 - 3.5)
	(D) Total respiratory (>64 years old)		250 (150 - 340)	2.4% (1.5 - 3.3)	-- -- -- -- -- --	-- -- -- -- -- --
		(E) COPD (>64 years old)	120 (80 - 150)	3.7% (2.5 - 4.7)	-- -- -- -- -- --	-- -- -- -- -- --
		(F) Pneumonia (>64 years old)	80 (50 - 100)	1.9% (1.3 - 2.6)	-- -- -- -- -- --	-- -- -- -- -- --
Hospital Admissions Cardiac	(G) Ischemic Heart Disease *** (>64 years old)		80 (30 - 120)	0.8% (0.3 - 1.3)	70 (30 - 120)	0.7% (0.3 - 1.2)
	(H) Congestive Heart Failure *** (>64 years old)		110 (50 - 160)	1.4% (0.7 - 2.1)	100 (50 - 150)	1.3% (0.6 - 2.0)
Lower Respiratory Symptoms in Children****	(I) Lower Respiratory Symptoms (# of cases) (8-12 year olds)		< 10000 > (8000 - 11000)	17.5% (15.3 - 19.6)	< 11000 > (6000 - 15000)	20.1% (10.3 - 28.3)
	(J) Lower Respiratory Symptoms (# of days) (9-11 year old asthmatics)		< 16000 > (6000 - 25000)	6.8% (2.4 - 10.9)	-- -- -- -- -- --	-- -- -- -- -- --
	(K) Doctor-diagnosed Acute Bronchitis associated with long-term exposure (10-12 year olds)		< 190 > (20 - 370)	0.3% (0.0 - 0.6)	-- -- -- -- -- --	-- -- -- -- -- --

* Health effects are associated with short-term exposure to PM, unless otherwise specified.

** Health effects incidence was quantified across the range of PM concentrations observed in each study, when possible, but not below background level. Background PM-10 is assumed to be 8 ug/m3; background PM-2.5 is assumed to be 3.5 ug/m3.

*** PM-2.5 results based on using PM-2.5 mass as PM-10 mass in the PM-10 functions.

****Angle brackets <> indicate incidence calculated using baseline incidence rates reported in studies, with no adjustment for location-specific incidence rates. This increases the uncertainty in the incidence estimates.

The numbers in parentheses for pooled functions are NOT standard confidence intervals.
All the numbers in parentheses are interpreted as 90% credible intervals based on uncertainty analysis that takes into account both statistical uncertainty and possible geographic variability.

Sources of Concentration-Response (C-R) Functions:
(A) PM-10 C-R function based on pooled results from studies in 10 locations; PM-2.5 C-R function based on pooled results from studies in six locations.
(B) Pope et al., 1995
(C) Thurston, et al., 1994
(D) PM-10 C-R based on pooled results from 4 functions
(E) PM-10 C-R based on pooled results from 4 functions
(F) PM-10 C-R based on pooled results from 4 functions
(G) Schwartz & Morris, 1995
(H) Schwartz & Morris, 1995
(I) Schwartz, et al., 1994
(J) Pope et al., 1991
(K) Dockery et al., 1989

The estimated mortality risks in Los Angeles County based on the pooled, short-term mortality functions and the long-term mortality functions expressed in either percentage terms or as number of deaths are roughly two to three times the risks estimated applying the same functions in Philadelphia County. The population of the Los Angeles County area used in the analysis is more than twice as large as Philadelphia County (3.6 million versus 1.6 million), however, the death rate is half of that observed in Philadelphia (667 versus 1280 per 100,000). The differences in population size and death rate between the two study areas are largely off-setting in terms of the risk calculations, but Los Angeles County PM annual levels are nearly double those observed in Philadelphia county. Thus, the differences in risk estimates between the two study areas appears to be largely due to differences in PM levels.

With respect to morbidity health endpoints, short-term exposures to PM concentrations in Los Angeles County are estimated to be associated with approximately 6.9% (CrI 4.2-9.4%) to 7.7% (CrI 2.1-13.4%) of total respiratory hospital admissions (all ages and individuals over 64, respectively). PM also is estimated to be associated with between 1.4% (CrI 0.6-2.3%) to 4.1%(CrI 2.0-6.1%) of cardiac hospital admissions among individuals over 64 years of age for ischemic heart disease and congestive heart failure.

Short-term exposure to PM in Los Angeles County is estimated to be associated with between 18.4% (CrI 6.9-28.0%) and 41.4% (CrI 37.2-45.2) of the lower respiratory symptoms reported in children 8-12 years in age, depending on PM indicator and the ages, races, and asthma status of the children. These incidences seem high, and EPA staff notes that questions can be raised about the transferability of concentration-response functions derived in eastern U.S. locations to Los Angeles. Therefore, risk estimates based on a recent study of asthmatic symptoms among African-American children in central Los Angeles are provided for comparison (Ostro et al., 1995). Estimates based on this study indicate that daily variations in PM concentrations are associated with 19.3% (CrI 6.4-29.2%) of the reported incidence of shortness of breath, which is similar to that derived from the other studies. Long-term exposure to PM over the course of the year is estimated to be associated with a 3.1% increase (CrI 0.4-4.7%) in incidence of doctor diagnosed acute bronchitis among 10-12 year olds.

Table VI-7. Estimated Annual Health Risks Associated with "As Is" PM Concentrations in Southeast Los Angeles County, 1995* (for base case assumptions)

Health Effects**			PM-10 Above Background*** Incidence	PM-10 Above Background*** Percent of Total Incidence	PM-2.5 Above Background*** Incidence	PM-2.5 Above Background*** Percent of Total Incidence
Mortality (all ages)	(A) Associated with short-term exposure		800 (570 - 1020)	3.3% (2.3 - 4.1)	900 (200 - 1560)	3.7% (0.8 - 6.3)
	(B) Associated with short-term exposure (study done in Los Angeles)		400 (40 - 750)	1.6% (0.2 - 3.1)	-- -- --	-- -- --
	(C) Associated with long-term exposure (51 locations)		-- -- --	-- -- --	2,920 (1850 - 3930)	11.9% (7.5 - 16.0)
Hospital Admissions Respiratory	(D) Total Respiratory (all ages)		-- -- --	-- -- --	1,200 (330 - 2080)	7.7% (2.1 - 13.4)
	(E) Total Respiratory (>64 years old)		1,070 (660 - 1460)	6.9% (4.2 - 9.4)	-- -- --	-- -- --
		(F) COPD (>64 years old)	440 (310 - 560)	10.3% (7.3 - 13.1)	-- -- --	-- -- --
		(G) Pneumonia (>64 years old)	420 (290 - 550)	5.6% (3.9 - 7.3)	-- -- --	-- -- --
Hospital Admissions Cardiac	(H) Ischemic Heart Disease**** (>64 years old)		260 (100 - 420)	2.3% (0.9 - 3.7)	160 (60 - 260)	1.4% (0.6 - 2.3)
	(I) Congestive Heart Failure**** (>64 years old)		290 (140 - 430)	4.1% (2.0 - 6.1)	180 (90 - 270)	2.5% (1.2 - 3.8)
Lower Respiratory Symptoms in Children *****	(J) Lower Respiratory Symptoms (# of cases) (8-12 year olds)		< 62000 > (56000 - 68000)	41.4% (37.2 - 45.2)	< 51000 > (28000 - 68000)	34.4% (19.1 - 45.7)
	(K) Lower Respiratory Symptoms (# of days) (9-11 year old asthmatics)		< 115000 > (43000 - 175000)	18.4% (6.9 - 28.0)	-- -- --	-- -- --
	(L) Days of shortness of breath (7-12 year old African American asthmatics in Los Angeles)		< 7200 > (2400 - 10900)	19.3% (6.4 - 29.2)	-- -- --	-- -- --
	(L) Doctor-diagnosed Acute Bronchitis associated with long-term exposure (10-12 year olds)		< 5090 > (680 - 7750)	3.1% (0.4 - 4.7)	-- -- --	-- -- --

* Southeast Los Angeles County was not in attainment of current PM-10 standards (50 ug/m3 annual average standard and 150 ug/m3 daily standard) in 1995. Figures shown use the actual reported concentrations.
** Health effects are associated with short-term exposure to PM, unless otherwise specified.
*** Health effects incidence was quantified across the range of PM concentrations observed in each study, when possible, but not below background level. Background PM-10 is assumed to be 6.0 ug/m3 and background PM-2.5 is assumed to be 2.5 ug/m3.
**** PM-2.5 results based on using PM-2.5 mass as PM-10 mass in the PM-10 functions.
*****Angle brackets <> indicate incidence calculated using baseline incidence rates reported in studies, with no adjustment for location-specific incidence rates. This increases the uncertainty in the incidence estimates.

The numbers in parentheses for pooled functions are NOT standard confidence intervals.
All numbers in parentheses are interpreted as 90% credible intervals based on uncertainty analysis that takes into account both statistical uncertainty and possible geographic variability.

Sources of Concentration-Response (C-R) Functions:
(A) PM-10 C-R function based on pooled results from studies in 10 locations; PM-2.5 C-R function based on pooled results from studies in six locations.
(B) Kinney et al.,1995
(C) Pope et al., 1995
(D) Thurston, et al., 1994
(E) PM-10 C-R based on pooled results from 4 functions
(F) PM-10 C-R based on pooled results from 4 functions
(G) PM-10 C-R based on pooled results from 4 functions
(H) Schwartz & Morris, 1995
(I) Schwartz & Morris, 1995
(J) Schwartz, et al., 1994
(K) Pope et al., 1991
(L) Dockery et al., 1989

c. <u>Key Uncertainties</u>

There are additional uncertainties about the risk estimates for both locations beyond those reflected in the credible intervals. These additional uncertainties include but are not limited to the degree of transferability of concentration-response functions and measurement error in air quality values for each location. Because national or community gathering of respiratory symptoms information is not routinely performed, the numbers of days or cases of symptoms is estimated by applying the percentage of incidence associated with PM to the baseline incidence rates reported in the health studies, which are from locations different than those being analyzed, with the exception of the Ostro et al. (1995) study. Baseline incidence may be considerably different from that observed in the cities analyzed, resulting in additional uncertainty pertaining to the numerical estimates of incidence reported in Tables VI-6 and VI-7. The estimates of percent incidence are less uncertain than the estimates of incidence counts for respiratory symptoms risk estimates in both Philadelphia and Los Angeles.

2. Base Case Risk Estimates Upon Attainment of Current Standards

For comparisons with alternative standards it is desirable to estimate health risks associated with PM air quality that does not include the effects of concentrations in excess of those allowed by the current national PM standards. For Philadelphia county, Table VI-6 also represents the estimated health risks associated with PM at or below the current PM_{10} standards, since the monitors used in estimating Philadelphia's air quality are already in attainment of the current PM_{10} standards. For Los Angeles County, however, the estimates given in Table VI-7 include contributions from concentrations in excess of those allowed by the current PM_{10} standards. The PM_{10} concentrations for the monitors used in the risk analysis in Los Angeles County have an annual mean controlling value of 52 $\mu g/m^3$ and a 2nd-daily max controlling value of 195 $\mu g/m^3$, versus the current PM_{10} standards of 50 $\mu g/m^3$ annual mean and 150 $\mu g/m^3$, 24-hr average. Adjusting PM air quality for Los Angeles County to simulate attainment of the current PM_{10} standards introduces additional uncertainty into the risk estimates, but is required in order to compare risks associated with attaining the current PM_{10} standards with risks associated with meeting alternative $PM_{2.5}$ standards.

The method chosen to simulate attainment of the current PM_{10} standards is to apply a proportional rollback to both PM_{10} and $PM_{2.5}$ concentrations (preserving the $PM_{2.5}/PM_{10}$ ratio) to air quality concentrations that "just attain" current standards (under current interpretation, this means reducing annual mean concentrations to 50.4 µg/m^3, and the second daily max concentration[6] to 154 µg/m^3, to reflect rounding conventions used to judge attainment). This modeling of attainment in Los Angeles County through proportional rollback contains two analytic assumptions. First, it assumes that the general shape of the distribution of PM air quality concentrations in Los Angeles County will remain the same as observed under the "as is" situation and that PM levels will be reduced proportionately based on the controlling standard. For Los Angeles County the 24-hr second daily max concentration of 195 µg/m^3 is the controlling value and needs to be reduced 21% to bring it into attaintment. Thus, the amount of each PM concentration above estimated background for the 1995 year in Los Angeles County was reduced by 21%. The second assumption is that the relationship between $PM_{2.5}$ and PM_{10} ($PM_{2.5}/PM_{10}$ ratio = 0.58) would be preserved as PM_{10} concentrations are reduced. If control strategies are used to reach attainment that preferentially controls coarse particles relative to fine particles (as has been observed in some areas, see Chapter IV), or that preferentially controls fine particles relative to coarse particles, this simplifying assumption introduces some inaccuracy. If the error is in the direction of not adequately reflecting a preferential control of coarse particles, then $PM_{2.5}$ concentrations in the "just attain PM_{10} standards case" would be expected to be higher than those estimated in this analysis. In this case, larger reductions in PM health risks would be expected than those reported later in the alternative standards risk analysis.

The results for Los Angeles County based on simulating attainment of the current PM_{10} standards are shown in Table VI-8. The reduction in PM concentrations results in an approximately 18-28% reduction in the risk estimates associated with short-term PM

---

[6] The current 24-hr standards are applied to the 4th highest daily concentration in a three year period. Since we are only examining a year of air quality concentrations in the risk analysis, the second daily max concentration was chosen as an approximate surrogate for the 4th highest concentration in three years value.

exposures compared to “as is” levels. This provides an example of how the estimated change in health

Table VI-8. Estimated Annual Health Risks Associated with Attainment of Current Standards in Southeast Los Angeles County, 1995* (for base case assumptions)

Health Effects**			Health Effects Associated with PM-10 Above Background***		Health Effects Associated with PM-2.5 Above Background***	
			Incidence	Percent of Total Incidence	Incidence	Percent of Total Incidence
Mortality (all ages)	(A) Associated with short-term exposure		630 (450 - 800)	2.6% (1.8-3.3)	710 (430 - 970)	2.9% (1.7 - 3.9)
	(B) Associated with short-term exposure (study done in Los Angeles)		290 (30 - 550)	1.2% (0.1 - 2.2)	-- -- --	-- -- --
	(C) Associated with long-term exposure (51 locations)		-- -- --	-- -- --	2,110 (1330 - 2860)	8.6% (5.4 - 11.7)
Hospital Admissions Respiratory	(D) Total Respiratory (all ages)		-- -- --	-- -- --	940 (250 - 1630)	6.1% (1.6 - 10.5)
	(E) Total Respiratory (>64 years old)		840 (520 - 1160)	5.4% (3.3 - 7.4)	-- -- --	-- -- --
		(F) COPD (>64 years old)	350 (240 - 440)	8.2% (5.8 - 10.5)	-- -- --	-- -- --
		(G) Pneumonia (>64 years old)	330 (230 - 430)	4.4% (3.1 - 5.8)	-- -- --	-- -- --
Hospital Admissions Cardiac	(H) Ischemic Heart Disease**** (>64 years old)		200 (80 - 330)	1.8% (0.7 - 2.9)	130 (50 - 200)	1.1% (0.4 - 1.8)
	(I) Congestive Heart Failure**** (>64 years old)		230 (110 - 340)	3.2% (1.5 - 4.8)	140 (70 - 210)	2.0% (1.0 - 3.0)
Lower Respiratory Symptoms in Children *****	(J) Lower Respiratory Symptoms (# of cases) (8-12 year olds)		< 52000 > (46000 - 57000)	34.8% (31.0 - 38.4)	< 43000 > (23000 - 58000)	28.7% (15.4 - 39.0)
	(K) Lower Respiratory Symptoms (# of days) (9-11 year old asthmatics)		< 93000 > (34000 - 143000)	14.9% (5.5 - 23.0)	-- -- --	-- -- --
	(L) Days of shortness of breath (7-12 year old African American asthmatics in Los Angeles)		< 5200 > (1700 - 8100)	14.1% (4.6 - 21.8)	-- -- --	-- -- --
	(L) Doctor-diagnosed Acute Bronchitis associated with long-term exposure (10-12 year olds)		< 3760 > (470 - 6190)	2.3% (0.3 - 3.7)	-- -- --	-- -- --

* Southeast Los Angeles County was not in attainment of current PM-10 standards (50 ug/m3 annual average standard and 150 ug/m3 daily standard) in 1995. "As is" daily PM-10 concentrations were first rolled back to simulate attainment of these standards. "As is" daily PM-2.5 concentrations were rolled back by the same percent as daily PM-10 concentrations. See text in Chapter VI for details.

** Health effects are associated with short-term exposure to PM, unless otherwise specified.

*** Health effects incidence was quantified across the range of PM concentrations observed in each study, when possible, but not below background level. Background PM-10 is assumed to be 6.0 ug/m3 and background PM-2.5 is assumed to be 2.5 ug/m3.

**** PM-2.5 results based on using PM-2.5 mass as PM-10 mass in the PM-10 functions.

*****Angle brackets <> indicate incidence calculated using baseline incidence rates reported in studies, with no adjustment for location-specific incidence rates. This increases the uncertainty in the incidence estimates.

The numbers in parentheses for pooled functions are NOT standard confidence intervals. All numbers in parentheses are interpreted as 90% credible intervals based on uncertainty analysis that takes into account both statistical uncertainty and possible geographic variability. See text in Chapter VI for details.

Sources of Concentration-Response (C-R) Functions:
(A) PM-10 C-R function based on pooled results from studies in 10 locations; PM-2.5 C-R function based on pooled results from studies in six locations.
(B) Kinney et al.,1995
(C) Pope et al., 1995
(D) Thurston, et al., 1994
(E) PM-10 C-R based on pooled results from 4 functions
(F) PM-10 C-R based on pooled results from 4 functions
(G) PM-10 C-R based on pooled results from 4 functions
(H) Schwartz & Morris, 1995
(I) Schwartz & Morris, 1995
(J) Schwartz, et al., 1994
(K) Pope et al., 1991
(L) Dockery et al., 1989

risks associated with PM is approximately equal to the amount of proportional air quality reduction required (for Los Angeles County, a reduction of 21% in air quality concentrations results in a 18-28% reduction in health risks associated with short-term exposures). This correspondence results from the shape of the concentration-response relationships reported in the literature and in the base case analysis, which are essentially linear over most of the range of concentrations considered here. For risks associated with long-term exposures, the reduction is greater than the relative change in PM levels because estimated health risks associated with long-term exposures are quantified relative to lowest observed annual mean concentrations in the health studies used in the risk analysis which are considerably in excess of background.

Although there are substantial uncertainties in predicting annual health risks associated with attainment of the current standards in Los Angeles County, the estimates in Table VI-8 suggest that short-term exposure to PM could be associated with approximately 1.2% (CrI 0.1-2.2%) to 2.9% (CrI 1.7-3.9%) of mortality, 5.4% (CrI 3.3-7.4%) of respiratory hospital admissions for those over 65, 1.1% (CrI 0.4-1.8%) to 3.2% (CrI 1.5-4.8%) of cardiac hospital admissions for ischemic heart disease and congestive heart failure, and from 14.9% (CrI 5.5-23.0%) to 34.8 (CrI 31.0-38.4%) of respiratory symptoms in children upon attainment of the current PM_{10} standards. Estimated mortality associated with long-term exposure is about 8.6% (CrI 5.4-11.7%) and doctor-diagnosed acute bronchitis associated with long-term exposure is about 2.3% (CrI 0.3-3.7%) upon attainment of the current NAAQS. However, in considering such estimates it is important to consider the substantial uncertainties that may affect these estimates. The next section summarizes the results of several sensitivity analyses to provide some insight into the magnitude of the uncertainties associated with the PM risk estimates. Additional uncertainties, not captured by the sensitivity analyses, were discussed previously in Section VI.B and VI.C.1.c.

3. Uncertainty Analyses of Estimated Risks Associated with "As Is" PM Levels in Philadelphia County and Attaining Current PM_{10} Standards in Los Angeles County

a. Sensitivity Analyses of Individual Key Uncertainties

A number of sensitivity analyses of the health risk model have been conducted to provide some perspective on the impact of various uncertainties and assumptions on the health risk estimates presented in this Staff Paper. These sensitivity analyses are presented in Appendix F and in the technical support document (Abt Associates, 1996b). Table VI-9 summarizes the results of a number of these sensitivity analysis indicating the effects of alternative specifications for several important air quality and concentration-response parameters (background, cutpoint concentrations, averaging time for mortality functions, and the effects of reduced slopes for long-term mortality functions resulting from the potential effects of inadequately considered confounders or previous air quality). The results are presented as a range of estimates of the percent of mortality and respiratory hospital admissions incidence associated with PM under "as is" air quality in Philadelphia County.

From Table VI-9 it can be seen that the estimates of health risks show particular sensitivity to assumptions concerning the use of appropriate cutpoint concentrations for quantifying risk.[7] The cutpoints used in the analysis can be used to inform judgments concerning the potential effects of nonlinear concentration-response relationships resulting from potential biological considerations, copollutant effects, or exposure misclassification associated with the use of ambient monitors as a measure of population exposures.

Disaggregating the pooled PM_{10} mortality analysis into subsets of studies with effects estimates based on more homogenous averaging times also can make substantial differences in the estimates of PM_{10} mortality health risk; for example, when studies with the shortest (1-day) and longest (3-5 day) averaging times are contrasted. As would be expected, assuming lower than reported coefficients for long-term mortality risk from PM exposures reduces risk estimates by an amount equal to the reduction in the coefficient. The estimates of health risks

[7]To quantify risks above various cutpoints, two alternative slope adjustment methods have been used to examine the potential impact of a concentration-response function having a steeper slope (i.e., larger RRs per µg) above specified cutpoints. See Figure VI-6 and discussion in Appendix F for further details.

associated with PM also show some degree of sensitivity to alternative specifications of background concentrations.

One important uncertainty that is not included in Table VI-9 concerns the effect of copollutants on the estimated risks associated with PM. The base case estimates risk resulting from concentration-response relationships developed without inclusion of copollutants. Since not all of the studies included in the base case analysis controlled for copollutants by simultaneously incorporating them in the analysis, it is not possible to directly estimate the sensitivity of the base case results by taking into account the effect of simultaneous inclusion of all copollutants in all studies. However, an examination of the sensitivity of risk estimates from individual studies that did include copollutants is provided in Appendix F, Table F-5b. The results for most, but not all, of the studies are consistent with the assessment in the CD that the magnitude of PM effects and their statistical uncertainty in many studies showed little sensitivity to the adjustment for copollutants (CD, p.13-55). As discussed in Section V.E., however, reanalyses of Philadelphia using TSP data by the HEI (Samet et al., 1996a) and Mooglavkar et al. (1995a,b) have reported a potential for more significant interaction by copollutants when multiple pollutants are entered into the concentration-response model. The implications of the perspective that PM may be serving as an index reflecting the effects of several pollutants in combination is discussed below in section VI.C.4 and is an area of uncertainty that needs to be investigated further.

Similar sensitivity analyses to the ones summarized above for Philadelphia County were performed for Los Angeles County. A primary point of interest is that the Los Angeles County risk estimates show less sensitivity to the choice of cutpoint than the Philadelphia County results, since a larger proportion of days in Los Angeles County have PM concentrations above some or all of the cutpoints analyzed (see exhibits 7.17 - 7.20 in Abt Associates, 1996b).

Table VI-9. Summary of Selected Sensitivity Analyses on Estimates of Risk Associated with PM in Philadelphia County

HEALTH ENDPOINT	PM Indicator	BASE CASE Central Estimate	SENSITIVITY ANALYSES Central Estimates				
			BACKGROUND[1] (Low-High Concentration)	**CUTPOINT**[2] Method I (Low-High)	**CUTPOINT**[2] Method II (Low- High)	**AVG TIME**[3] (5 day-1 day)	**SLOPE REDUCTION**[4] Long-Term Study
MORTALITY Short-Term Exposure	PM_{10}	**1.1%**	1.3 - 0.9%	0.4 - 0.1%	0.4 - 0.1%	1.8 -0.4%	---
	$PM_{2.5}$	**1.8%**	2.0 - 1.6%	1.1 - 0.1%	1.0 - 0.1.%	---	---
MORTALITY Long-Term Exposure	$PM_{2.5}$	**4.6%**	No change[5]	2.4 - 0%[6]		---	3.4 - 2.3%
HOSPITAL ADMISSIONS Total Respiratory[7]	PM_{10}	**2.4%**	2.9 - 1.9%	1.3 - 0.4%	1.0 - 0.2%	---	---
	$PM_{2.5}$	**2.0%**	2.3 - 1.8%	1.4 - 0.4%	1.2 - 0.2%	---	---

[1] Low = 5 µg/m^3 PM_{10}, 2 µg/m^3 $PM_{2.5}$; High = 11 µg/m^3 PM_{10}, 5 µg/m^3 $PM_{2.5}$; Base Case = 8 µg/ m^3 PM_{10}, 3.5 µg/m^3 $PM_{2.5}$.

[2] Low = 20 µg/m^3 PM_{10}, 10 µg/m^3 $PM_{2.5}$; High = 40 ug/m^3 PM_{10}, 30 µg/m^3 $PM_{2.5}$; Base Case = linear relationship above background. Method I and Method II refer to methods of adjusting the slope of the concentration-response relationship above the cutpoint upwards to different extents to reflect the anticipated effect of a "hockey stick"-style threshold concentration response function. See Appendix F for further details..

[3] 5 day = results using 3-5 day averaging time studies; 1 day = result using single day averaging time study; Base Case used 2 day averaging time.

[4] First number represents effect of 33% reduction in slope; second number represents effect of 50% reduction in slope; Base Case used relative risk as reported in study (i.e., no adjustment). Slope Reduction intended to roughly model potential effects of previous air quality or uncontrolled confounding.

[5] Background concentration sensitivity analyses make no difference in the risk estimates for mortality from long-term exposure since the lowest observed concentrations in this studies (the limit to which the concentration-response function was applied) was well above background.

[6] Low = 12.5 µg/m^3 $PM_{2.5}$; High = 18 µg/m^3 $PM_{2.5}$; Base Case = linear relationship above the lowest observed concentration in study (9 µg/m3). No slope adjustment was made to the long-term mortality concentration-response relationship when applying the cutpoints.

[7] Total Respiratory Hospital Admissions for those > 64 yrs of age for PM_{10}; for all ages for $PM_{2.5}$

In general, these sensitivity analyses indicate that alternative analytic choices within the range of those considered in this analysis may lead to sizable differences in risk estimates. However, these are also primarily intended as bounding exercises to characterize the magnitude of potential uncertainty, and as such do not reflect judgments concerning the likelihood of specific alternative cases tested.

b. Integrated Uncertainty Analysis

In addition to individual sensitivity analyses discussed above, an integrated uncertainty analysis has been conducted for mortality associated with short-term exposures to $PM_{2.5}$ to assess the potential combined effects of several key uncertainties simultaneously. Through Monte Carlo sampling approaches, a distribution of values for several key parameters in the model has been estimated or specified, and 90 percent credible intervals have been generated representing the probability that the risk estimates fall within a particular range once the combined effect of these uncertainties have been considered. An advantage of this approach is that it allows the combined effect of several uncertainties to be quantitatively estimated. A major difficulty of the approach, however, is that the method inherently requires an estimate of the distribution of values for each uncertainty included, even if little empirical evidence is available to inform what is an appropriate choice for each distribution. Since there is little information on which to base some of the distributions and/or weightings chosen to represent certain key parameters in the integrated uncertainty analyses, the results of this analysis should be viewed as illustrative in character. The purpose of the analysis is to show the potential sensitivity of the risk estimates when several uncertainties, rather than just a single uncertainty, are considered simultaneously.

As discussed earlier in this Chapter, there are a number of uncertainties encountered as one attempts to estimate health risks associated with PM levels for a given city or location. Given the availability of specific data for baseline health effects incidence and daily PM air quality data for the two locations examined (i.e., Philadelphia and Los Angeles Counties), staff judges that the uncertainties associated with these two inputs to the risk model are relatively small compared to the uncertainties associated with what is the appropriate concentration-response function for these locations. Therefore, the integrated uncertainty analysis is primarily focused on the concentration-response uncertainties, since this is judged to be the largest source of uncertainty in the health risk model. In addition, uncertainty about background levels and uncertainty about how PM air quality distributions might change upon attainment of alternative standards also is included in the analysis.

Table VI-10 below summarizes how each of the uncertainties incorporated into the integrated uncertainty analysis is treated. As outlined in Appendix E, there is substantial uncertainty concerning whether cutpoint concentrations above background exist based on a review of the available data. As discussed previously in this Chapter and in Appendix E, various approaches have been used to derive cutpoints of interest from the available data. The current data does not provide strong evidence concerning where a cutpoint concentration might exist (CD). To account for this state of uncertainty, the integrated uncertainty analysis use several illustrative weightings to assess the possible effects of this important uncertainty in combination with other key uncertainties (i.e., estimated background levels, air quality rollback approach). Each of the key uncertainties were incorporated sequentially into the analysis to illustrate the impact of each uncertainty on the risk estimates.

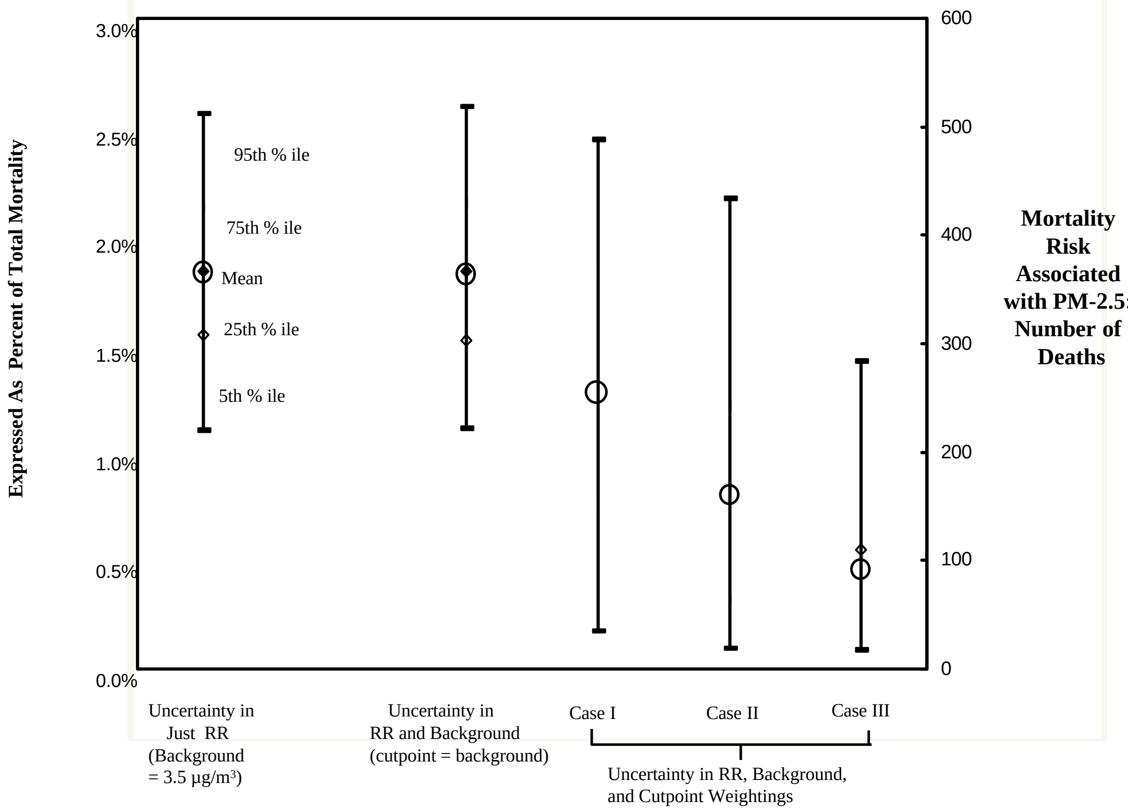
Figure VI-7 displays the results of the integrated uncertainty analysis for mortality associated with short-term exposure to $PM_{2.5}$ for Philadelphia County under the “as is” scenario. The risk estimates are expressed in terms of both number of deaths over a 1-year period and as a percent of total mortality. Each vertical bar represents a set of risk estimates that includes the uncertainties identified below the bars. The mean estimate is given, as well as the 5th, 25th, 75th, and 95th percentiles. The first vertical bar includes only uncertainty in the RR and assumes that background equals 3.5 $\mu g/m^3$. The second vertical bar incorporates uncertainty in RR and in the $PM_{2.5}$ background concentration for Philadelphia, with the cutpoint set equal to the background concentration. The final three vertical bars incorporate uncertainties about RR, background, and three weighting schemes differentially weighting the likelihood that various cutpoint (or threshold) concentrations exist. The three weighting schemes are indicated in the box below Figure VI-7. Case I represents a judgment that concentration-response functions are more likely to exist down to background or 10 $\mu g/m^3$; Case III represents a judgment that concentration-response functions are more likely to have a

Table VI-10. Summary of Uncertainties Incorporated Into Integrated Uncertainty Analysis

Uncertainty	Distribution
Coefficient (β) in concentration-response function	Based on distribution of β's obtained from pooled results of $PM_{2.5}$ mortality studies in six locations
Cutpoints in concentration-response function	Four cutpoints (background, 10, 18, 30 $\mu g/m^3$) with three discrete weighting schemes and two slope adjustment methods
Background $PM_{2.5}$ concentration	Uniform distribution on the intervals [2,5] and [1,4] ($\mu g/m^3$) for Philadelphia County and Los Angeles County, respectively, based on the estimated ranges identified in the CD for the Eastern and Western sections of the United States
Shape of $PM_{2.5}$ air quality distribution upon attainment of alternative standards	Based on distribution of regression slope of linear rollback over background to ratio of second high 24-hr $PM_{2.5}$ values for 129 pairs of site-years of data (see Section 8.2 in Abt Associates (1996b))

Figure VI-7. Effect of Several Uncertainties on Mortality Risk Associated With Short-Term Exposure to PM-2.5 in Philadelphia County

September 1992 - August 1993
(Population: 1.6 Million)



Uncertainty in background concentration enters into these calculations only when the cutpoint is set equal to background. The other cutpoints are greater than the highest background concentration considered.

Cutpoint Weighting Schemes

	Case I	Case II	Case III
Background	0.5	0.2	0.05
10 μg/m^3	0.3	0.3	0.15
18 μg/m^3	0.15	0.3	0.5
30 μg/m^3	0.05	0.2	0.3

cutpoint at 18 or 30 μg/m^3; and Case II represents a judgment that concentration-response functions are somewhat more likely to have cutpoints in the 10-18 μg/m^3 range.[8] Figure VI-8 shows a similar figure for Los Angeles County where attainment of the current PM_{10} standards is simulated.

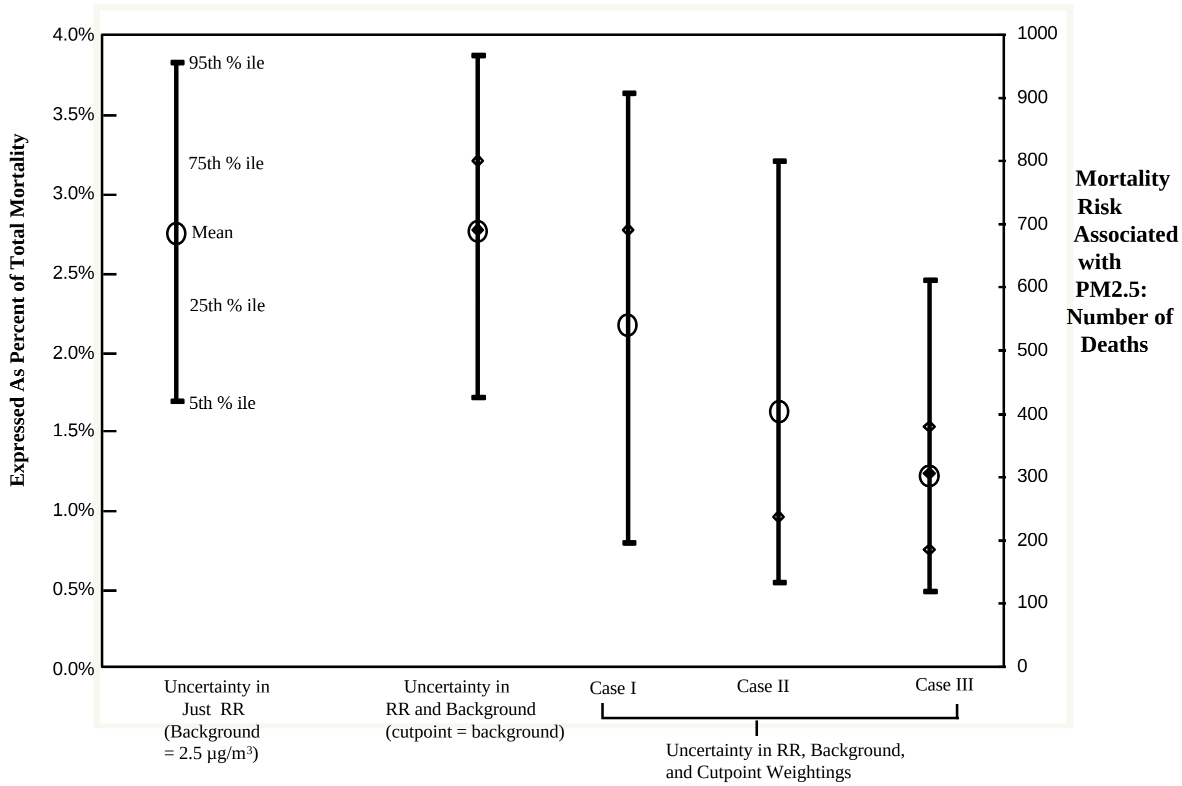
The results of the integrated uncertainty analysis illustrate the impact on the mortality risk estimates of whether or not one judges there to be a likely cutpoint or threshold above estimated background levels. If one assumes no cutpoint above background, mortality associated with short-term exposure in Philadelphia County under the "as is" scenario is estimated to be about 1.8 (CrI 1.2-2.7) percent of total mortality or 375 (CrI 225-525) excess deaths. Allowing for the possibility of a cutpoint above estimated background levels, three alternative cutpoint weighting schemes reduce the mean risk estimates to about 1.3, 0.8, and 0.5 percent of total mortality for Cases I, II, and III, respectively. For Cases I and II the 90 percent credible intervals also become considerably wider than the risk estimates incorporating only uncertainty in the RR slope and estimated background concentration and all three cutpoint weighting schemes indicate a lower bound of the 90 percent credible interval of about 0.2-0.3 percent of total mortality. For Los Angeles County under the just attaining the current PM_{10} standards, the mean mortality risk estimates assuming no cutpoint is about 2.8 percent (CrI 1.7-3.8). The alternative cutpoint weighting schemes reduce the mean mortality risk estimates to about 2.2, 1.6, and 1.2 percent for Cases I, II, and III, respectively. The higher risk estimates in Los Angeles County are due mainly to the higher $PM_{2.5}$ levels, since Philadelphia County air quality is lower (i.e., better) than the current PM_{10} standards.

---

[8] In the sensitivity analysis described previously in the Chapter two different methods for adjusting the slope of the concentration-response function were examined when various cutpoints (or thresholds) were analyzed. In the integrated uncertainty analysis, the two slope adjustment methods were given equal weight.

Figure VI-8. Effect of Several Uncertainties on Mortality Risk Associated With Short-Term Exposure to PM-2.5 After Meeting Current PM-10 Standards in Los Angeles County

(Population: 3.6 Million)



Uncertainty in background concentration enters into these calculations only when the cutpoint is set equal to background. The other cutpoints are greater than the highest background concentration considered.

Cutpoint Weighting Schemes

	Case I	Case II	Case III
Background	0.5	0.2	0.05
10 μg/m^3	0.3	0.3	0.15
18 μg/m^3	0.15	0.3	0.5
30 μg/m^3	0.05	0.2	0.3

4. Risk Estimates Associated with Alternative $PM_{2.5}$ Standards

This section presents risk estimates associated with just attaining several alternative $PM_{2.5}$ standards for the Philadelphia and Los Angeles County study areas. In addition to risk estimates using base case assumptions, individual sensitivity analyses and integrated uncertainty analyses also are presented, analogous to the approach used for the "as is" risk estimates. The additional uncertainty introduced primarily by adjusting air quality to reflect future attainment of alternative standards also is discussed.

a. Base Case Risk Estimates

Table VI-11a summarizes the air quality information indicating which monitor in each location has the "controlling value" for a rollback to attain 24-hr or annual mean alternative standards.[9] Table VI-11b shows the amount of reduction in air quality required to attain the alternative $PM_{2.5}$ standard, and which standard of the combination, daily or annual, is "controlling" (i.e., requires the larger reduction in concentration). To model attainment of alternative $PM_{2.5}$ standards, a proportional rollback approach is used as the base case. Although it is extremely difficult to predict what patterns of air quality would be observed in these two locations upon attaining alternative $PM_{2.5}$ standards, a preliminary investigation of changes in $PM_{2.5}$ air quality observed over the past 15 years of limited monitoring reported to the AIRS database finds that the general pattern of air quality changes observed is a proportional change in both daily and annual mean concentrations (Abt Associates, 1996b). The estimated effects of alternative assumptions concerning patterns of air quality rollback are presented in Table VI-14.

Tables VI-12a and VI-12b show the risk estimates for just attaining alternative $PM_{2.5}$ standards in Philadelphia County, and Tables VI-13a and VI-13b show the risk estimates for just attaining alternative $PM_{2.5}$ standards in Los Angeles County using base case assumptions. Similar to the approach used to model attainment of the current PM_{10} standards in Los Angeles

[9] The terminology of "controlling value" and "controlling monitor" are used here as synonyms for the well-known terms "design value" and "design value monitors". The monitors used in the risk analysis are not genuine design value monitors established for particular air sheds, and thus the alternative terminology is used to avoid confusion.

Table VI-11a. **Controlling Monitors for Rollbacks to Attain Alternative PM-2.5 Standards**

Monitor Site	Weighted Annual Average $PM_{2.5}$ Concentration*	Second Daily Maximum 24-Hour $PM_{2.5}$ Concentration*	Controlling Monitor
Philadelphia County			
N/E	16	65	
PBY	17	72	For daily standard
TEM	17	70	For annual standard
Southeast Los Angeles County			
Central LA	24	91	For annual standard
Diamond Bar	22	102	For daily standard

All concentrations are given in $\mu g/m^3$.

*Both weighted annual averages and second daily maximum concentrations at the two monitors in Southeast Los Angeles County were adjusted to reflect attainment of the current PM_{10} annual standard of 50 $\mu g/m^3$ and the current PM_{10} daily standard of 150 $\mu g/m^3$. These standards are currently attained in Philadelphia County.

Table VI-11b. Controlling Standards and Percent Rollbacks Necessary to Attain Alternative $PM_{2.5}$ Standards

Alternative PM-2.5 Standards		**Philadelphia County**	**Southeast Los Angeles County**
Annual Avg. Standard	24-Hour Standard	Controlling Standard and Percent Rollback*	Controlling Standard and Percent Rollback**
20 alone		----	Annual -- 18.8%
20	65	Daily -- 10.4%	Daily -- 37.0%
20	50	Daily -- 32.3%	Daily -- 52.1%
20	25	Daily -- 68.7%	Daily -- 77.3%
15 alone		Annual -- 15.5%	Annual -- 42.0%
15	65	Annual -- 15.5%	Annual -- 42.0%
15	50	Daily -- 32.3%	Daily -- 52.1%
15	25	Daily -- 68.7%	Daily -- 77.3%

All concentrations are given in $\mu g/m^3$.

*Based on controlling values for Philadelphia County of 17 $\mu g/m^3$ for the annual standard and 72 $\mu g/m^3$ for the daily standard.

** Based on controlling values for Southeast Los Angeles County of 24 $\mu g/m^3$ for the annual standard and 102 $\mu g/m^3$ for the daily standard.

Table VI-12a. Estimated Changes in Health Risks Associated with Meeting Alternative PM-2.5 Standards in Philadelphia County, September 1992 - August 1993 (for base case assumptions)

Health Effects*		PM-2.5-Associated Incidence associated with current standards**	Incidence Associated with Meeting Alternative Standards: 20 ug/m3 annual	20 ug/m3 annual and 65 ug/m3 daily	20 ug/m3 annual and 50 ug/m3 daily	20 ug/m3 annual and 25 ug/m3 daily
Mortality (all ages)	(A) Associated with short-term exposure	370 (220 - 510)	370 (220 - 510)	330 (200 - 460)	250 (150 - 340)	110 (70 - 160)
	Percent Reduction in PM-Associated Incidence:*** **Percent Reduction in Total Incidence:******		0.0% 0.0%	10.8% 0.2%	32.4% 0.6%	70.3% 1.3%
	(B) Associated with long-term exposure	920 (580 - 1260)	920 (580 - 1260)	750 (440 - 960)	390 (230 - 490)	0 (0 - 0)
	Percent Reduction in PM-Associated Incidence: **Percent Reduction in Total Incidence:**		0.0% 0.0%	18.5% 0.8%	57.6% 2.6%	100.0% 4.6%
Hospital Admissions Respiratory	(C) Total Respiratory (all ages)	260 (70 - 450)	260 (70 - 450)	230 (60 - 400)	180 (50 - 300)	80 (20 - 140)
	Percent Reduction in PM-Associated Incidence: **Percent Reduction in Total Incidence:**		0.0% 0.0%	11.5% 0.2%	30.8% 0.6%	69.2% 1.4%
Hospital Admissions Cardiac	(D) Ischemic Heart Disease***** (>64 years old)	70 (30 - 120)	70 (30 - 120)	60 (30 - 110)	50 (20 - 80)	20 (10 - 40)
	(E) Congestive Heart Failure***** (>64 years old)	100 (50 - 150)	100 (50 - 150)	90 (40 - 130)	70 (30 - 100)	30 (20 - 40)
	Range of Percent Reductions in PM-Associated Incidence: **Range of Percent Reductions in Total Incidence:**		0.0% - 0.0% 0.0% - 0.0%	10.0% - 14.3% 0.1% - 0.1%	28.6% - 30.0% 0.2% - 0.4%	70.0% - 71.4% 0.5% - 0.9%
(F) Lower Respiratory Symptoms (8-12 yr. olds) ******		< 11000 > (6000 - 15000)	< 11000 > (6000 - 15000)	< 10000 > (5000 - 13000)	< 7000 > (4000 - 9000)	< 3000 > (2000 - 4000)
	Percent Reduction in PM-Associated Incidence: **Percent Reduction in Total Incidence:**		0.0% 0.0%	9.1% 1.8%	36.4% 7.3%	72.7% 14.6%

* Health effects are associated with short-term exposure to PM, unless otherwise specified.

** Health effects incidence was quantified across the range of PM concentrations observed in each study, when possible, but not below background PM-2.5 level. Background PM-2.5 is assumed to be 3.5 ug/m3 in Philadelphia County.

*** The percent reduction in PM-associated incidence achieved by attaining alternative standards as opposed to the current standards is the reduction in incidence divided by the incidence associated with current standards. For example, the percent reduction in PM-associated incidence of mortalit associated with short-term exposure to PM-2.5 achieved by meeting both a 15 ug/m3 annual and a 65 ug/m3 daily standard is (370-330)/370=10.8%.

**** The percent reduction in total incidence achieved by attaining current or alternative standards is the reduction in incidence achieved by attaining the standard divided by the total (not only PM-associated) incidence.

***** PM-2.5 results based on using PM-2.5 mass as PM-10 mass in the PM-10 functions.

******Angle brackets <> indicate incidence calculated using baseline incidence rates reported in studies, with no adjustment for location-specific incidence rates. This increases the uncertainty in the incidence estimates.

Sources of Concentration-Response (C-R) Functions:
(A) C-R function based on pooled results from studies in six locations.
(B) Pope et al., 1995
(C) Thurston, et al., 1994
(D) Schwartz & Morris, 1995
(E) Schwartz & Morris, 1995
(F) Schwartz, et al., 1994

The numbers in parentheses for pooled functions are NOT standard confidence intervals. All the numbers in parentheses are interpreted as 90% credible intervals based on Monte Carlo analysis that takes into account both statistical uncertainty and possible geographic variability. See text in Chapter VI for details.

Table VI-12b. Estimated Changes in Health Risks Associated with Meeting Alternative PM-2.5 Standards in Philadelphia County, September 1992 - August 1993 (for base case assumptions)

Health Effects*		PM-2.5-associated Incidence associated with current standards**	Incidence Associated with Meeting Alternative Standards: 15 ug/m3 annual	15 ug/m3 annual and 65 ug/m3 daily	15 ug/m3 annual and 50 ug/m3 daily	15 ug/m3 annual and 25 ug/m3 daily
Mortality (all ages)	(A) Associated with short-term exposure	370 (220 - 510)	310 (190 - 430)	310 (190 - 430)	250 (150 - 340)	110 (70 - 160)
	Percent Reduction in PM-Associated Incidence:* **		16.2%	16.2%	32.4%	70.3%
	Percent Reduction in Total Incidence:****		0.3%	0.3%	0.6%	1.3%
Mortality (all ages)	(B) Associated with long-term exposure	920 (580 - 1260)	660 (390 - 850)	660 (390 - 850)	390 (230 - 490)	0 (0 - 0)
	Percent Reduction in PM-Associated Incidence:		28.3%	28.3%	57.6%	100.0%
	Percent Reduction in Total Incidence:		1.3%	1.3%	2.6%	4.6%
Hospital Admissions Respiratory	(C) Total Respiratory (all ages)	260 (70 - 450)	220 (60 - 380)	220 (60 - 380)	180 (50 - 300)	80 (20 - 140)
	Percent Reduction in PM-Associated Incidence:		15.4%	15.4%	30.8%	69.2%
	Percent Reduction in Total Incidence:		0.3%	0.3%	0.6%	1.4%
Hospital Admissions Cardiac	(D) Ischemic Heart Disease***** (>64 years old)	70 (30 - 120)	60 (30 - 100)	60 (30 - 100)	50 (20 - 80)	20 (10 - 40)
	(E) Congestive Heart Failure***** (>64 years old)	100 (50 - 150)	80 (40 - 130)	80 (40 - 130)	70 (30 - 100)	30 (20 - 40)
	Range of Percent Reductions in PM-Associated Incidence:		14.3% - 20.0%	14.3% - 20.0%	28.6% - 30.0%	70.0% - 71.4%
	Range of Percent Reductions in Total Incidence:		0.1% - 0.3%	0.1% - 0.3%	0.2% - 0.4%	0.5% - 0.9%
(F) Lower Respiratory Symptoms (8-12 yr. olds) ******		< 11000 > (6000 - 15000)	< 9000 > (5000 - 12000)	< 9000 > (5000 - 12000)	< 7000 > (4000 - 9000)	< 3000 > (2000 - 4000)
	Percent Reduction in PM-Associated Incidence:		18.2%	18.2%	36.4%	72.7%
	Percent Reduction in Total Incidence:		3.6%	3.6%	7.3%	14.6%

* Health effects are associated with short-term exposure to PM, unless otherwise specified.
** Health effects incidence was quantified across the range of PM concentrations observed in each study, when possible, but not below background PM-2.5 level. Background PM-2.5 is assumed to be 3.5 ug/m3 in Philadelphia County.
*** The percent reduction in PM-associated incidence achieved by attaining alternative standards as opposed to the current standards is the reduction in incidence divided by the incidence associated with current standards. For example, the percent reduction in PM-associated incidence of mortality associated with short-term exposure to PM-2.5 achieved by meeting both a 15 ug/m3 annual and a 65 ug/m3 daily standard is (370 - 310)/370 = 16.2%.
**** The percent reduction in total incidence achieved by attaining current or alternative standards is the reduction in incidence achieved by attaining the standard divided by the total (not only PM-associated) incidence.
***** PM-2.5 results based on using PM-2.5 mass as PM-10 mass in the PM-10 functions.
******Angle brackets <> indicate incidence calculated using baseline incidence rates reported in studies, with no adjustment for location-specific incidence rates. This increases the uncertainty in the incidence estimates.

Sources of Concentration-Response (C-R) Functions:
(A) C-R function based on pooled results from studies in six locations.
(B) Pope et al., 1995
(C) Thurston, et al., 1994
(D) Schwartz & Morris, 1995
(E) Schwartz & Morris, 1995
(F) Schwartz, et al., 1994

The numbers in parentheses for pooled functions are NOT standard confidence intervals. All the numbers in parentheses are interpreted as 90% credible intervals based on Monte Carlo analysis that takes into account both statistical uncertainty and possible geographic variability. See text in Chapter VI for details.

Table VI-13a. Estimated Changes in Health Risks Associated with Meeting Alternative PM-2.5 Standards in Southeast Los Angeles County, 1995* (for base case assumptions)

Health Effects		PM-2.5-Related Incidence associated with current standards**	Incidence Associated with Meeting Alternative Standards			
			20 ug/m3 annual	20 ug/m3 annual and 65 ug/m3 daily	20 ug/m3 annual and 50 ug/m3 daily	20 ug/m3 annual and 25 ug/m3 daily
Mortality (all ages)	(A) Associated with short-term exposure	710 (430 - 970)	560 (350 - 780)	430 (270 - 600)	310 (210 - 460)	120 (100 - 220)
	Percent Reduction in PM-Associated Incidence:* **		21.1%	39.4%	56.3%	83.1%
	Percent Reduction in Total Incidence:******		0.6%	1.1%	1.6%	2.4%
	(B) Associated with long-term exposure	2110 (1330 - 2860)	1540 (980 - 2080)	940 (600 - 1260)	480 (310 - 640)	0 (0 - 0)
	Percent Reduction in PM-Associated Incidence:		27.0%	55.5%	77.3%	100.0%
	Percent Reduction in Total Incidence:		2.3%	4.8%	6.6%	8.6%
Hospital Admissions Respiratory	(C) Total Respiratory (all ages)	940 (250 - 1630)	750 (200 - 1320)	570 (160 - 1030)	410 (120 - 780)	160 (50 - 370)
	Percent Reduction in PM-Associated Incidence:		20.2%	39.4%	56.4%	83.0%
	Percent Reduction in Total Incidence:		1.2%	2.4%	3.4%	5.0%
Hospital Admissions Cardiac	(D) Ischemic Heart Disease ***** (>64 years old)	130 (50 - 200)	100 (40 - 160)	80 (30 - 120)	60 (20 - 90)	20 (10 - 40)
	(E) Congestive Heart Failure ***** (>64 years old)	140 (70 - 210)	110 (60 - 170)	80 (40 - 130)	60 (30 - 100)	20 (20 - 40)
	Range of Percent Reductions in PM-Associated Incidence:		21.4% - 23.1%	38.5% - 42.9%	53.8% - 57.1%	84.6% - 85.7%
	Range of Percent Reductions in Total Incidence:		0.3% - 0.4%	0.4% - 0.8%	0.6% - 1.1%	1.0% - 1.7%
(F) Lower Respiratory Symptoms (8-12 yr. olds)******		< 43000 > (23000 - 58000)	< 32000 > (18000 - 43000)	< 23000 > (14000 - 31000)	< 16000 > (10000 - 22000)	< 6000 > (5000 - 9000)
	Percent Reduction in PM-Associated Incidence:		25.6%	46.5%	62.8%	86.0%
	Percent Reduction in Total Incidence:		7.3%	13.3%	18.0%	24.7%

Health effects are associated with short-term exposure to PM, unless otherwise specified.

* Los Angeles County was not in attainment of current PM-10 standards in 1995. Figures shown assume actual PM-10 concentrations are first rolled back to simulate attainment of these standards, and that actual PM-2.5 concentrations are rolled back by the same percent as PM-10. See text in Chapter VI for details.

** Health effects incidence was quantified across the range of PM concentrations observed in each study, when possible, but not below background PM-2.5 level. Background PM-2.5 is assumed to be 2.5 ug/m3 in Southeast Los Angeles County.

*** The percent reduction in PM-associated incidence achieved by attaining alternative standards as opposed to the current standards is the reduction in incidence divided by the incidence associated with current standards. For example, the percent reduction in PM-associated incidence of mortality associated with short-term exposure to PM-2.5 achieved by meeting both a 20 ug/m3 annual and a 65 ug/m3 daily standard is (710 - 420)/710 = 40.8%.

**** The percent reduction in total incidence achieved by attaining current or alternative standards is the reduction in incidence achieved by attaining the standard divided by the total (not only PM-associated) incidence.

***** PM-2.5 results based on using PM-2.5 mass as PM-10 mass in the PM-10 functions.

******Angle brackets <> indicate incidence calculated using baseline incidence rates reported in studies, with no adjustment for location-specific incidence rates. This increases the uncertainty in the incidence estimates.

Sources of Concentration-Response (C-R) Functions:
(A) C-R function based on pooled results from studies in 6 locations
(B) Pope et al., 1995
(C) Thurston, et al., 1994
(D) Schwartz & Morris, 1995
(E) Schwartz & Morris, 1995
(F) Schwartz, et al., 1994

The numbers in parentheses for pooled studies are NOT standard confidence intervals. All the numbers in parentheses are interpreted as 90% credible intervals based on Monte Carlo analysis that takes into account both statistical uncertainty and possible geographic variability. See text in Chapter VI for details.

Table VI-13b. Estimated Changes in Health Risks Associated with Meeting Alternative PM-2.5 Standards in Southeast Los Angeles County, 1995* (for base case assumptions)

Health Effects		PM-2.5-Related Incidence associated with current standards**	Incidence Associated with Meeting Alternative Standards 15 ug/m3 annual	15 ug/m3 annual and 65 ug/m3 daily	15 ug/m3 annual and 50 ug/m3 daily	15 ug/m3 annual and 25 ug/m3 daily
Mortality (all ages)	(A) Associated with short-term exposure	710 (430 - 970)	390 (250 - 560)	390 (250 - 560)	310 (210 - 460)	120 (100 - 220)
	Percent Reduction in PM-Associated Incidence:*** **Percent Reduction in Total Incidence:******		45.1% 1.3%	45.1% 1.3%	56.3% 1.6%	83.1% 2.4%
	(B) Associated with long-term exposure	2110 (1330 - 2860)	810 (520 - 1090)	810 (520 - 1090)	480 (310 - 640)	0 (0 - 0)
	Percent Reduction in PM-Associated Incidence: **Percent Reduction in Total Incidence:**		61.6% 5.3%	61.6% 5.3%	77.3% 6.6%	100.0% 8.6%
Hospital Admissions Respiratory	(C) Total Respiratory (all ages)	940 (250 - 1630)	520 (140 - 950)	520 (140 - 950)	410 (120 - 780)	160 (50 - 370)
	Percent Reduction in PM-Associated Incidence: **Percent Reduction in Total Incidence:**		44.7% 2.7%	44.7% 2.7%	56.4% 3.4%	83.0% 5.0%
Hospital Admissions Cardiac	(D) Ischemic Heart Disease ***** (>64 years old)	130 (50 - 200)	70 (30 - 110)	70 (30 - 110)	60 (20 - 90)	20 (10 - 40)
	(E) Congestive Heart Failure ***** (>64 years old)	140 (70 - 210)	80 (40 - 120)	80 (40 - 120)	60 (30 - 100)	20 (20 - 40)
	Range of Percent Reductions in PM-Associated Incidence: **Range of Percent Reductions in Total Incidence:**		42.9% - 46.2% 0.5% - 0.8%	42.9% - 46.2% 0.5% - 0.8%	53.8% - 57.1% 0.6% - 1.1%	84.6% - 85.7% 1.0% - 1.7%
(F) Lower Respiratory Symptoms (8-12 yr. olds)******		< 43000 > (23000 - 58000)	< 21000 > (13000 - 28000)	< 21000 > (13000 - 28000)	< 16000 > (10000 - 22000)	< 6000 > (5000 - 9000)
	Percent Reduction in PM-Associated Incidence: **Percent Reduction in Total Incidence:**		51.2% 14.7%	51.2% 14.7%	62.8% 18.0%	86.0% 24.7%

Health effects are associated with short-term exposure to PM, unless otherwise specified.

* Los Angeles County was not in attainment of current PM-10 standards in 1995. Figures shown assume actual PM-10 concentrations are first rolled back to simulate attainment of these standards, and that actual PM-2.5 concentrations are rolled back by the same percent as PM-10. See text in Chapter VI for details.

** Health effects incidence was quantified across the range of PM concentrations observed in each study, when possible, but not below background PM-2.5 level. Background PM-2.5 is assumed to be 2.5 ug/m3 in Southeast Los Angeles County.

*** The percent reduction in PM-associated incidence achieved by attaining alternative standards as opposed to the current standards is the reduction in incidence divided by the incidence associated with current standards. For example, the percent reduction in PM-associated incidence of mortality associated with short-term exposure to PM-2.5 achieved by meeting both a 15 ug/m3 annual and a 65 ug/m3 daily standard is (710-390)/710 = 45.1%.

**** The percent reduction in total incidence achieved by attaining current or alternative standards is the reduction in incidence achieved by attaining the standard divided by the total (not only PM-associated) incidence.

***** PM-2.5 results based on using PM-2.5 mass as PM-10 mass in the PM-10 functions.

****** Angle brackets <> indicate incidence calculated using baseline incidence rates reported in studies, with no adjustment for location-specific incidence rates. This increases the uncertainty in the incidence estimates.

Sources of Concentration-Response (C-R) Functions:
(A) C-R function based on pooled results from studies in 6 locations.
(B) Pope et al., 1995
(C) Thurston, et al., 1994
(D) Schwartz & Morris, 1995
(E) Schwartz & Morris, 1995
(F) Schwartz, et al., 1994

The numbers in parentheses for pooled studies are NOT standard confidence intervals. All the numbers in parentheses are interpreted as 90% credible intervals based on Monte Carlo analysis that takes into account both statistical uncertainty and possible geographic variability. See text in Chapter VI for details.

Table VI-14. Sensitivity Analysis: Effect of Alternative Rollback Methods on Mortality Estimates Short-term Exposure (Pooled Function) and Long-term Exposure PM-2.5 Mortality Functions Philadelphia County, September 1992 - August 1993

Initial Air Quality: 16.3 ug/m3 annual average, 69.3 ug/m3 2nd daily maximum

		Percent Change in PM-Associated Incidence		Portion of Proportional Rollback Incidence Reduction Achieved by Alternative Rollback
	Alternative Standard	**All PM concentrations rolled back equally**	Higher PM concentrations reduced more	
(A) Mortality associated with short-term exposure	15 ug/m3 annual	10.6%	9.2%	86.4%
	50 ug/m3 daily	29.7%	18.6%	62.6%
(B) Mortality associated with long-term exposure	15 ug/m3 annual	19.4%	19.4%	100.0%
	50 ug/m3 daily	54.1%	39.3%	72.6%

* Health effects incidence was quantified across the range of PM concentrations observed in each study, but not below background PM-2.5 level, which is assumed to be 3.5 ug/m3.

(A) C-R function based on studies in 6 cities
(B) Pope et al., 1995

County, alternative $PM_{2.5}$ standards have been modeled based on the amount of air quality reduction required to meet the numerical value of the controlling standard. Rounding conventions to be applied to any $PM_{2.5}$ standards have not been determined yet, and so the effect of rounding conventions has not been incorporated into this analysis of alternative standards. Several points from these Tables are of particular interest:

- Daily standards control the air quality reduction, and thus the estimated health risk reductions observed, for almost all of the alternative standards scenarios (Table VI-11b). In Philadelphia, which has an "as-is" annual mean concentration close to 15 $\mu g/m^3$, an annual standard of 20 $\mu g/m^3$ has no effect on reducing estimated incidence of health effects (Table VI-12a). Attaining an annual standard of 15 $\mu g/m^3$ without a daily standard is estimated to result in reductions in air quality concentrations and health risks (about 14-20% reduction for effects associated with short-term exposures and about 28% reduction for mortality associated with long-term exposure). However, the estimated reductions in health risks associated with attaining the 50 $\mu g/m^3$ 24-hr standard are significantly higher (e.g., about 29-36% reduction in mortality and other health effects associated with short-term exposures and about 58% reduction in mortality associated with long-term exposure upon attaining a 50 $\mu g/m^3$ 24-hr standard). Attaining a 25 $\mu g/m^3$ 24-hr standard in Philadelphia County is estimated to result in the largest risk reductions (e.g., about 69-73% reduction in mortality and other health effects associated with short-term exposures and 100% reduction in mortality associated with long-term exposures to PM).
- In Los Angeles County, an annual standard of 20 $\mu g/m^3$ is estimated to reduce air quality concentrations about 19%, with all three of the 24-hr alternative standards (65 $\mu g/m^3$, 50 $\mu g/m^3$, and 25 $\mu g/m^3$) requiring considerably greater reductions. A 15 $\mu g/m^3$ annual standard controls the amount of air quality reduction and estimated health risk reduced for the case involving a 65$\mu g/m^3$ alternative 24-hr standard, but not for cases involving a 50 $\mu g/m^3$ or 25 $\mu g/m^3$ alternative 24-hr standard. An annual standard of 15 $\mu g/m^3$ alone reduces estimated health risks associated with PM about 43-51% for

mortality and other health effects associated with short-term exposure and about 62% for mortality associated with long-term exposure relative to just attaining the current PM_{10} standards in Los Angeles County. Attaining a 50 µg/m^3 24-hr standard reduces estimated health risks associated with PM about 54-63% for mortality and other health effects associated with short-term exposure and about 77% for mortality associated with long-term exposure. Attaining a 25 µg/m^3 24-hr standard is estimated to further reduce health risks relative to the current PM_{10} standards, with about a 83-86% reduction in mortality and other health effects associated with short-term exposure and a 100% reduction in mortality associated with long-term exposure. As expected, the estimated health risk reductions are larger for Los Angeles County than Philadelphia County due to the higher PM air quality levels associated with meeting the current PM_{10} standards (i.e., baseline air quality in Philadelphia is below the level required to meet the current standards).

- The proportion of estimated risk associated with reductions in $PM_{2.5}$ under alternative standard scenarios can be considered either as a percentage in the PM-associated incidence reduced or as a percentage of total incidence of that health endpoint due to PM and all other causes. As an example, standards of 15 µg/m^3 and 50 µg/m^3 24-hr in Philadelphia County lead to an estimated 32% reduction in mortality associated with short-term exposures to PM and a 29-36% reduction in morbidity (hospital admissions and respiratory symptoms) associated with short-term exposures to PM. These changes result in reductions in the overall incidence rates of these endpoints that are considerably smaller. For example, a 32% reduction in mortality associated with short-term PM exposures leads to an estimated 0.6% reduction in the total mortality incidence.
- Estimates of the reduction in total annual incidence of mortality upon attainment of alternative standards are more uncertain than estimates of the reduction in total annual incidence of other health effects, as a consequence of uncertainties in the extent of mortality displacement (shortening of life) that may be associated with PM (see Section V.C.1.c; CD, pp. 13-44-45). These uncertainties concerning the degree of mortality

displacement are not as salient for estimates of reductions in annual mortality incidence associated with long-term PM exposures compared to short-term PM exposures, since the type of study design that produced the long-term exposure concentration-response functions provides findings that indicate effects on annual mortality rates (Utell and Frampton, 1995). However, depending on assumptions concerning the biological lags and cumulative effects of air pollution involved in these long-term exposure studies, uncertainty is involved concerning how long an area would need to be in attainment of an alternative standard in order for the full measure of estimated mortality rate reduction to be realized.

- Greater percent reduction of PM-associated risks is estimated for mortality associated with long-term exposures to PM than from short-term exposures. This is the consequence of quantifying increases in mortality associated with long-term exposures only at concentrations considerably above background ($PM_{2.5}$ concentrations > 9 $\mu g/m^3$ based on Pope et al. (1995)).

b. Individual Sensitivity Analysis Concerning Air Quality Rollbacks

The estimates of risk reductions in Tables VI-12 and VI-13 particularly depend on what inherently must be assumptions about the pattern of air quality reductions that will be observed in the future in attaining the alternative standard cases. While the base model used assumes a proportional reduction would be observed in all $PM_{2.5}$ concentrations above background as a consequence of control strategies intended to meet a controlling annual mean or 24-hr standard, it is quite possible that substantial differences in $PM_{2.5}$ air quality reductions could occur across the $PM_{2.5}$ distribution.[10] An attempt to bound the potential effects of these possible alternative rollbacks has been examined in a sensitivity analysis of PM-associated

[10] Information on past reductions of $PM_{2.5}$ concentrations as a direct result of NAAQS is not available, given that prior and current ambient standards for particles regulated larger particle indicators (TSP, PM_{10}). Existing monitoring information can be examined instead, although it is uncertain how much of the variation observed will reflect actual control strategies versus more general year-to-year variability. In a preliminary examination of changes in the distribution of $PM_{2.5}$ concentrations from sites with multiple years of data (from AIRS and CARB data sets), Abt Associates found that while a proportional rollback was a reasonable approximation of the central tendency of variation observed, considerable variation in this relationship was observed (see Abt Associates, 1996b for more information).

mortality risks by choosing alternative assumptions for modeling $PM_{2.5}$ rollbacks. The results of this sensitivity analysis are presented in Table VI-14. The alternative reduction approach provided for illustration decreases the upper 10% of $PM_{2.5}$ 24-hr air quality concentrations by a larger amount (a ratio of 1.6) than the reductions in the remaining 90% of the distribution of PM air quality concentrations and is intended to model a control strategy that preferentially targets peak PM levels.

The results of the sensitivity analysis in Table VI-14 indicate that estimated mortality risks reduced by annual $PM_{2.5}$ standards are largely insensitive to the pattern of rollbacks in $PM_{2.5}$ concentrations, whereas estimates of risk associated with alternative 24-hr $PM_{2.5}$ standards are somewhat more sensitive to the choice of rollback methodology.

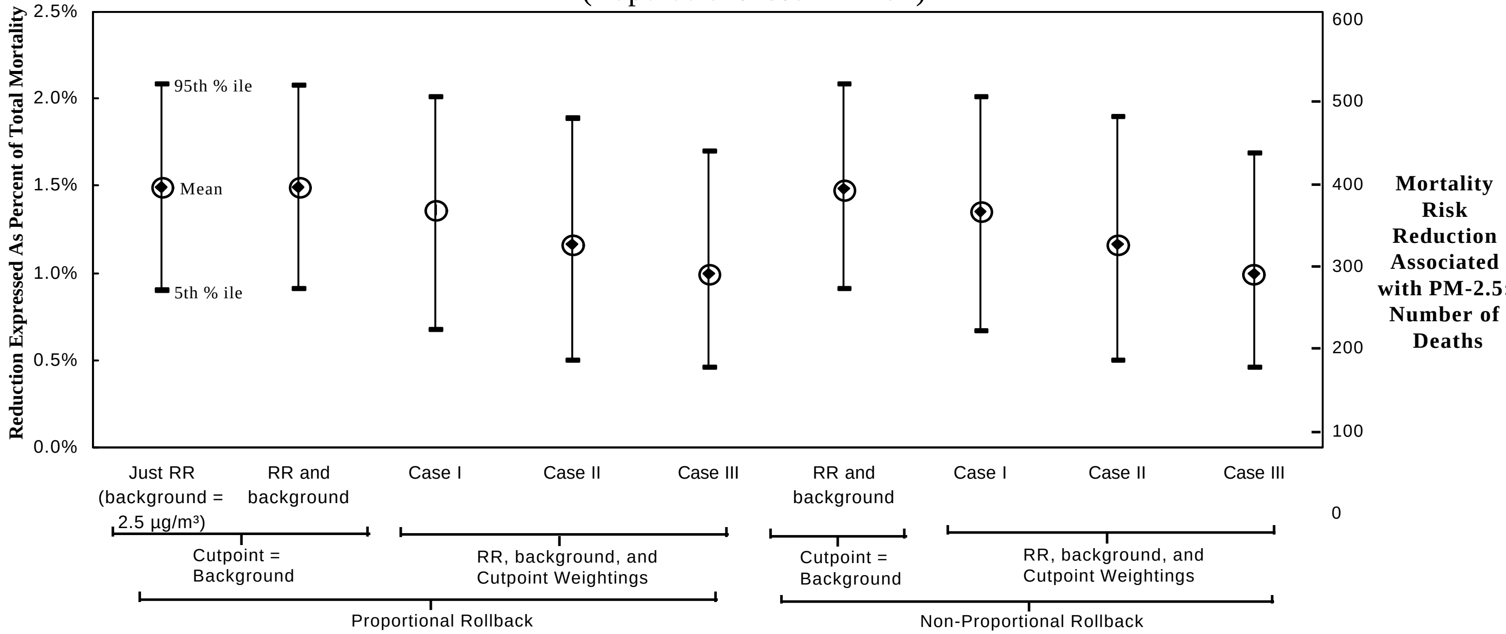
c. Integrated Uncertainty Analysis

Using the same approach described previously in Section VI.C.3.b, an illustrative integrated uncertainty analysis was prepared for estimating the reduction in mortality risk associated with short-term exposures upon attainment of example alternative $PM_{2.5}$ standards in Los Angeles County. These risk reductions were calculated relative to the scenario where Los Angeles County just attains the current PM_{10} standards. Figure VI-9 displays the results of the integrated uncertainty analysis for attaining example $PM_{2.5}$ standards of 15 $\mu g/m^3$, annual average and 50 $\mu g/m^3$, 24-hour average in Los Angeles County. Several sources of uncertainty were progressively included from left to right in the figure. The first vertical line reflects only uncertainty in the RR. The second vertical line includes uncertainty in RR and estimated background concentration, but no cutpoints are included. The next three vertical lines incorporate uncertainty about cutpoints, using the same three cutpoint weighting schemes discussed previously in Section VI.C.3.b and employs a proportional rollback method to simulate attainment of the $PM_{2.5}$ standards. The last three vertical lines also incorporate uncertainty about cutpoints, but use a non-proportional rollback approach to simulate attainment of the $PM_{2.5}$ standards.

As was observed in the earlier integrated uncertainty analysis, uncertainty about cutpoints has the largest impact on the estimated risk reduction associated with alternative standards. In contrast, the use of a proportional or non-proportional rollback method appears

Figure VI-9. Effect of Several Uncertainties on Reductions in Mortality Risk Associated With Short-Term Exposure to PM-2.5 Upon Attaining PM-2.5 Standards of 15 μg/m³ Annual and 50 μg/m³ Daily in Los Angeles County

(Population: 3.6 Million)



Cutpoint Weighting Schemes

	Case I	Case II	Case III
Background	0.5	0.2	0.05
10 μg/m³	0.3	0.3	0.15
18 μg/m³	0.15	0.3	0.5
30 μg/m³	0.05	0.2	0.3

to have only a slight impact on the estimated risk reduction for mortality associated with short-term exposure to $PM_{2.5}$ when placed in the context of the other uncertainties that also affect our ability to predict risk reductions from alternative $PM_{2.5}$ standards.

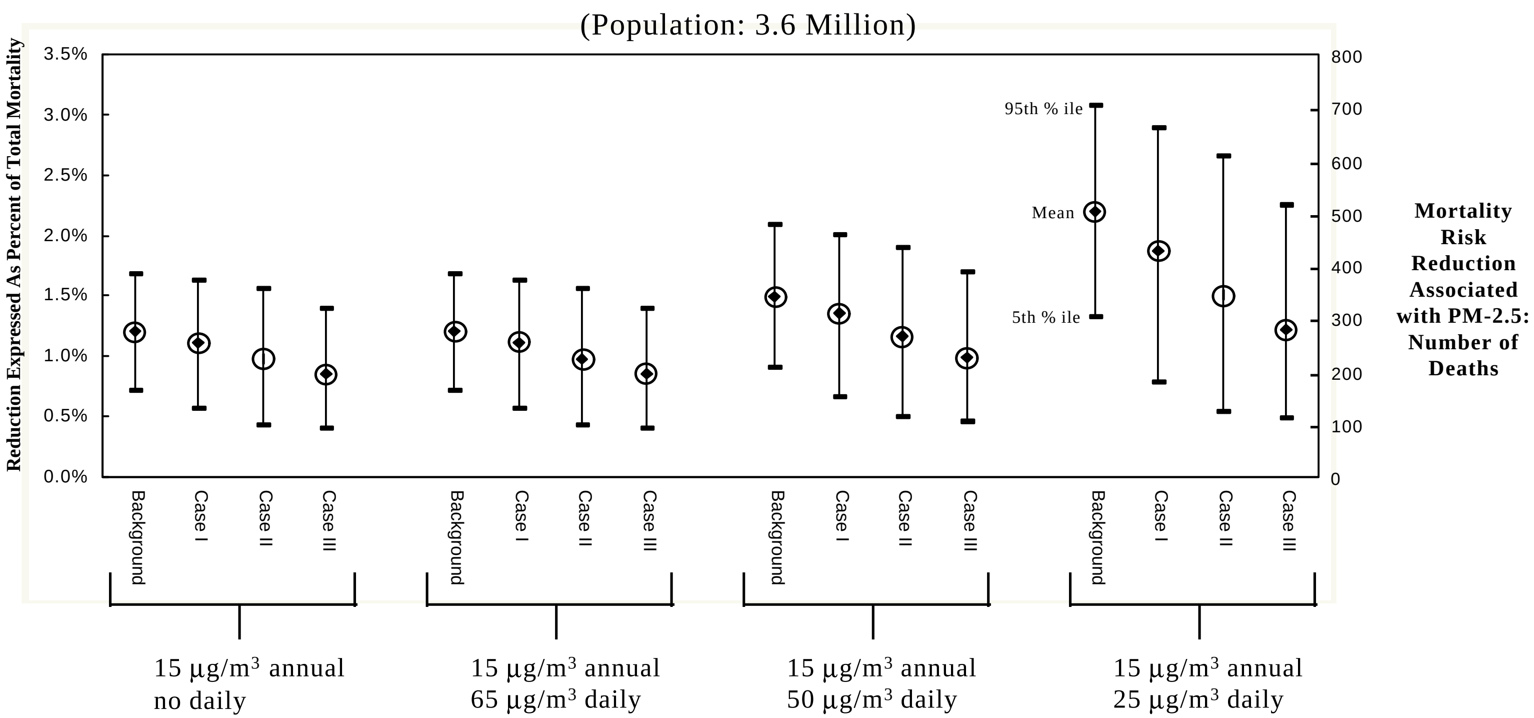
In addition to the uncertainties inherent in estimating risks for the as is scenarios, such as the relative risk, background, and cutpoint uncertainties assessed in the integrated uncertainty analyses, estimates of reductions in risk resulting from attainment of alternative $PM_{2.5}$ standards are subject to uncertainties related to the projection of air quality that would occur when alternative standards are attained. These uncertainties relate in part to the potential that $PM_{2.5}$ may be serving in varying degrees as an index for air pollution (either by indexing the effects of other gaseous copollutants in addition to $PM_{2.5}$, or by indexing relatively more harmful constituents within $PM_{2.5}$). Such uncertainties may serve to alter estimates of risk reduction associated with attainment of alternative $PM_{2.5}$ standards, and the anticipated effects of potential strategies used to reduce PM concentrations.

Figure VI-10 displays the results of the integrated uncertainty analysis for Los Angeles County associated with attainment of several alternative PM2.5 standards. Four sets of standards are included: an annual standard alone set at 15 $\mu g/m^3$, and three pairs of standards with an annual standard set at 15 $\mu g/m^3$ accompanied by a 24-hour standards set at 65, 50, or 25 $\mu g/m^3$. In this figure, each set of four vertical lines represents the estimated risk reduction where uncertainties about background, RR, and cutpoint, and form of rollback have been included. The first vertical line in each group, labeled "background", assumes a cutpoint set equal to background, while the next three lines represent the three different cutpoint weighting schemes described previously and listed in the table at the bottom of the figure.

The estimated risk reduction associated with the 15 $\mu g/m^3$ annual standard alone is the same as that associated with this annual standard coupled with a 65 $\mu g/m^3$ daily standard,

because the annual standard is the controlling standard. The greatest risk reduction is associated with the 15 $\mu g/m^3$ annual, 25 $\mu g/m^3$ daily standards pair. For this standard combination, the estimated mean risk reduction is about 2.2% (CrI 1.3-3.0) of total mortality or about 500 (CrI 300-700) excess deaths avoided when the cutpoint is set equal to the estimated background concentration level. Under the alternative cutpoint weighting schemes,

Figure VI-10. Effect of Several Uncertainties on Reductions in Mortality Risk Associated With Short-Term Exposure to PM-2.5 Upon Meeting Alternative PM-2.5 Standards in Los Angeles County



Cutpoint Weighting Schemes

	Case I	Case II	Case III
Background	0.5	0.2	0.05
10 μg/m³	0.3	0.3	0.15
18 μg/m³	0.15	0.3	0.5
30 μg/m³	0.05	0.2	0.3

the estimated mean risk reduction for this same suite of standards is reduced to about 1.2 to 1.8% of total mortality (or about 290-430 excess deaths avoided) depending on the weighting scheme used. As discussed previously, the percent reduction in total mortality can be expressed as either a percentage of total mortality due to all causes as shown on Figures VI-9 and VI-10 or as a percent reduction in the PM-associated mortality. For example, a reduction of 1.5% in total mortality (or 400 deaths) corresponds to a 56% reduction in PM-associated excess mortality and a 1.0% decrease in total mortality (or 300 deaths) corresponds to a 42% reduction in PM-associated mortality.

5. Key Observations from the Risk Analyses

This Chapter has presented a summary of a PM health risk assessment that quantifies health risks associated with 1) existing air quality levels, 2) projected air quality levels that would occur upon attainment of the current PM_{10} standards, and 3) projected air quality that would occur upon attainment of several alternative $PM_{2.5}$ standards in two urban areas. Summarized below are key observations resulting from the risk analyses, as well as several important caveats and limitations:

1) Fairly wide ranges of risk estimates result for mortality and morbidity health effects in the two locations analyzed when the effects of key uncertainties and alternative assumptions are considered.

2) In the staff's judgment, estimates of mortality and morbidity risks remain significant from a public health perspective when the current PM_{10} standards are attained.

These points are illustrated below for mortality risks using base case and alternative assumptions as well as for morbidity risks using base case assumptions. For example, risk of mortality from short-term $PM_{2.5}$ exposures upon attainment of the current standards was estimated to range from approximately 400 to 1,000 deaths a year in Los Angeles County (population = 3.6 million) under base case assumptions, and from approximately 100 to 1,000 deaths across alternative assumptions considered in the integrated uncertainty analysis. For Philadelphia County (population = 1.6 million), a city with more moderate air quality already well below the current standards, mortality risk associated with short-term $PM_{2.5}$ exposures ranged from approximately 200 to 500 deaths under base case assumptions, and from approximately 20 to 500 deaths under alternative assumptions. In addition, risks of morbidity effects associated with exposures to $PM_{2.5}$ are estimated to center around approximately a thousand hospital admissions and many thousands of cases of respiratory symptoms in children per year for Los Angeles, with several hundred hospital admissions and thousands of cases of respiratory symptoms estimated for Philadelphia (mean estimates of base case assumptions).

3) Attainment of the range of alternative $PM_{2.5}$ standards considered was estimated to lead to essentially no changes in PM-associated risk to very substantial changes, depending on the city and the levels of the standards.

Mortality and morbidity risks associated with short-term PM exposures in Los Angeles County are estimated to be reduced by roughly 20-25% upon attainment of an annual $PM_{2.5}$ standard of 20 $\mu g/m^3$ and 45-50% for an annual standard of 15 $\mu g/m^3$ beyond the risks associated with attainment of the current PM_{10} standards when base case assumptions are used.   Under alternative assumptions, a greater proportion of PM-associated risk would be expected to be reduced (although reductions in the absolute incidence of health effects may be less).   Daily standards ranging from 65 $\mu g/m^3$ to 25 $\mu g/m^3$ would reduce PM-associated risks from roughly 40% to 85% beyond those associated with attainment of the current PM_{10} standards when base case assumptions are used. For an area already within attainment of the current standards (Philadelphia County), risk reductions are estimated upon attainment of an annual standard of 15 $\mu g/m^3$ (of roughly 15-20%) and attainment of 24-hr standards of 65 to 25 $\mu g/m^3$ (ranging from 10-70%, respectively), for base case assumptions.

4) Based on the results from the sensitivity analyses of key uncertainties and the integrated uncertainty analyses, the single most important factor influencing the uncertainty associated with estimates of PM health risk is whether or not a cutpoint concentration exists below which PM health risks are not likely to occur.

Alternative cutpoint concentrations considered for these analyses could result in as much as a 3 to 4-fold difference in estimated risk associated with PM exposures in Los Angeles County (Figure VI-8, see also Exhibits 7.19 and 7.20, Abt Associates, 1996b) depending on the degree of confidence one imputed to the likelihood that a $PM_{2.5}$ cutpoint concentration existed at the highest concentrations evaluated relative to the base case assumptions. In an area with PM concentrations well below the current PM standards (e.g., Philadelphia County), differences in "as is" risk for alternative cutpoint assumptions may be even greater, since these locations would be expected to have a greater proportion of air quality values below the cutpoint concentration.

5) Based on results from the sensitivity analysis of key uncertainties and/or the integrated uncertainty analyses, quantitative consideration of the following uncertainties have a much more modest impact on the risk estimates: inclusion of individual copollutant species when estimating PM effect sizes; the choice of approach to adjusting the slope in analyzing alternative cutpoints; the value chosen to represent average annual background PM concentrations; and the choice of rollback adjustment approaches for simulating attainment of alternative PM standards.

6) Risk analyses of alternative standard scenarios incorporate several additional sources of uncertainty, including: uncertainty in the pattern of air quality concentration reductions that would be observed across the distribution of PM concentrations in areas attaining the standards ("rollback uncertainty") and uncertainty concerning the degree to which current PM risk coefficients may reflect contributions from other pollutants, or the particular contribution of certain constituents of $PM_{2.5}$, and whether such constituents would be reduced in similar proportion to the reduction in $PM_{2.5}$ as a whole.

To the extent concentrations of other combustion source copollutants are reduced more or less than $PM_{2.5}$ concentrations in attaining alternative $PM_{2.5}$ standards, estimates of health risk reduced by alternative $PM_{2.5}$ standards would be expected to vary in proportion to the degree to which such copollutants have a genuine role in producing, or modifying the ability of PM to produce, some of the health effects associated with PM in current concentration-response relationships. Similarly, if specific constituents of $PM_{2.5}$ mass have differing potencies in producing health effects relative to other $PM_{2.5}$ constituents, estimates of risk reduced would be expected to vary if these constituent concentration are reduced to different degrees by control strategies designed to attain alternative $PM_{2.5}$ standards.